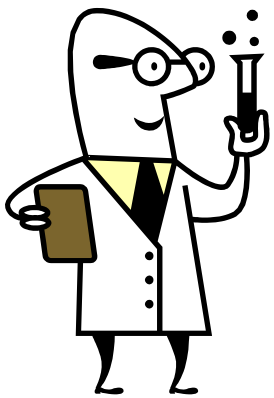
Accounting for Scientists: Tevatron Luminosity



Vladimir Shiltsev
Fermilab AD/Tevatron

Content:

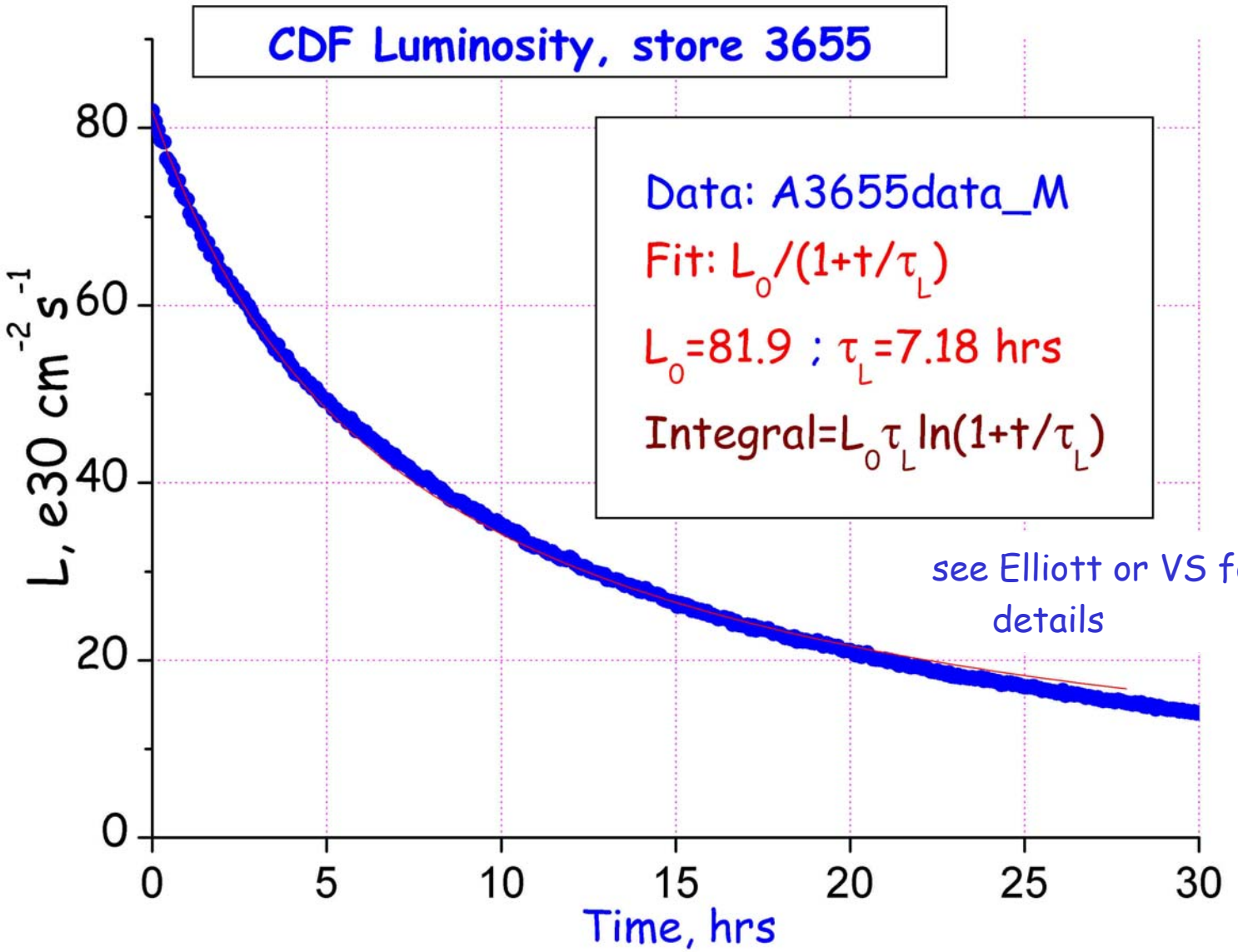
- Introduction: (ir)relevant comments
- Luminosity progress:
  - 2002-2003
  - Shutdown'03 - Mar'04
  - Mar'04 – July '04
  - Shutdown'04 – May'05
- Open Questions and Conclusions

Introductory Notes: Lumi and Integral

$$L = \frac{3\gamma \ f_0 \ B \ N_{\bar{p}} N_p}{\pi\beta^* \left(\varepsilon_p + \varepsilon_{\bar{p}}\right)} H\left(\sigma_l / \beta^*\right)$$

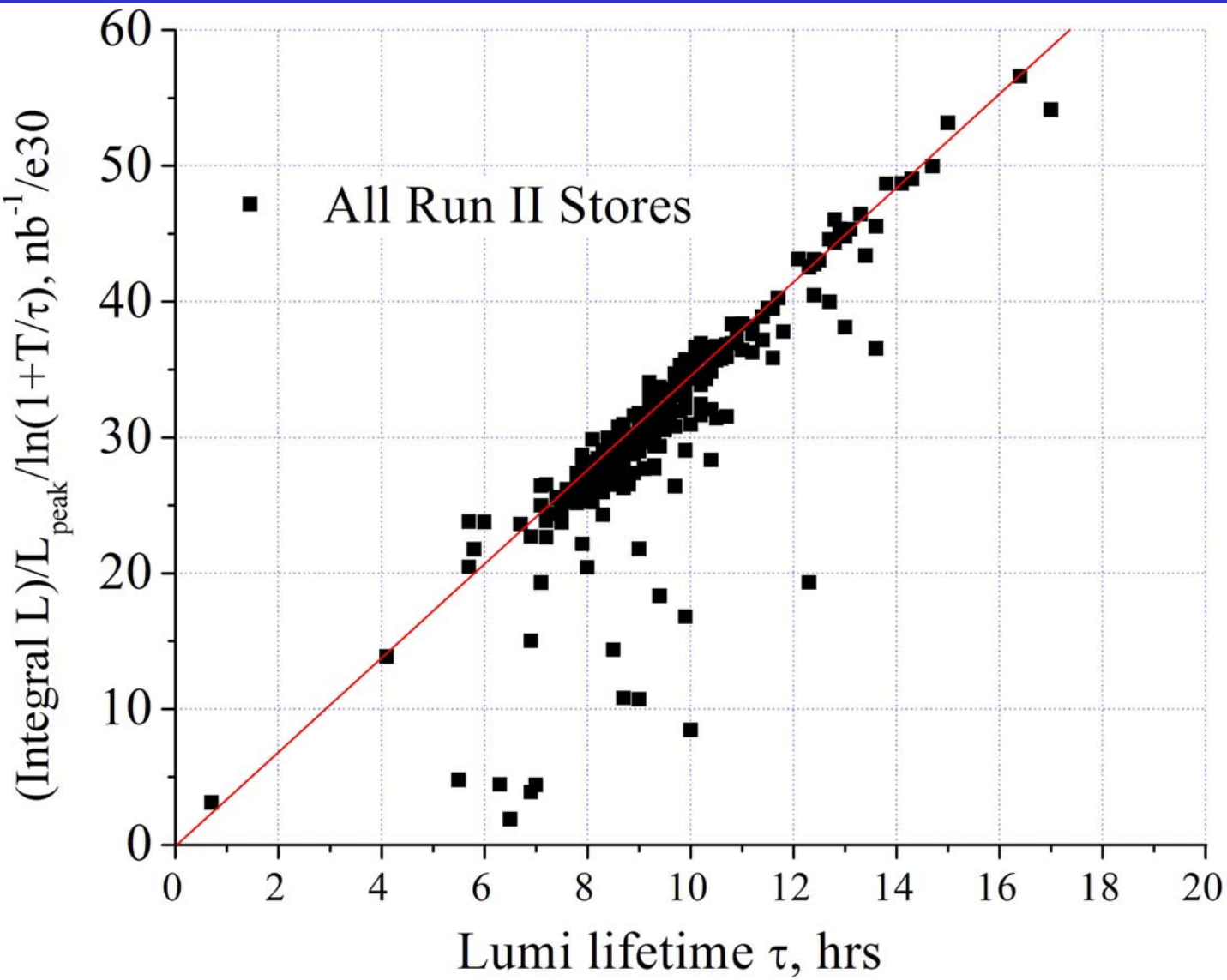
- Peak Luminosity: primary factors
  - Beta* at IP and bunchlength: H(x)/beta^*
  - Emittances
  - Number of protons: N_p
  - Number of antiprotons: BN_{pbar}

Integral: Log in time, $\propto L_0$ and Lifetime

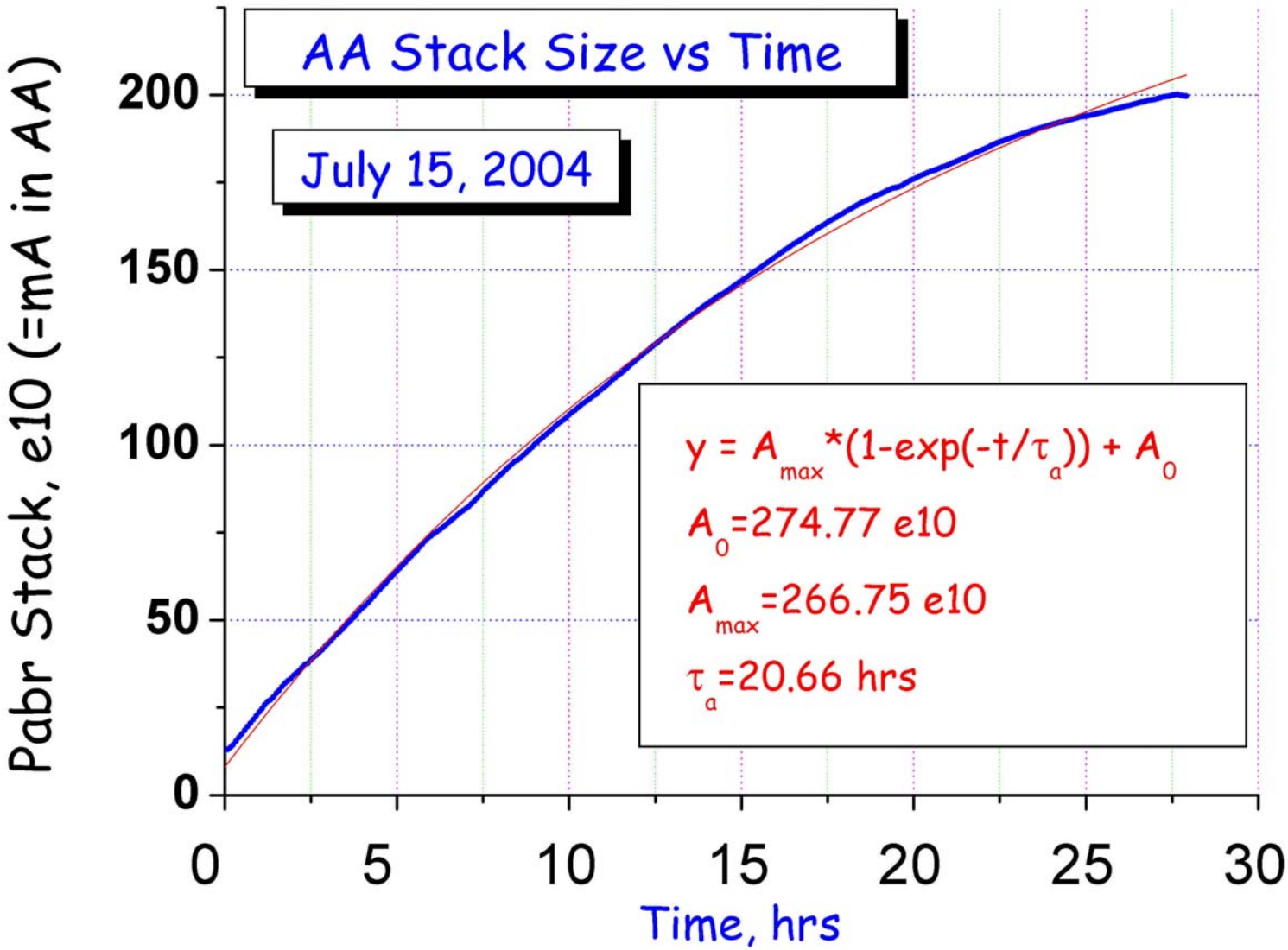


see Elliott or VS for more details

Integral Is Indeed as Mentioned Above:



Integral: N_a Exponentially Saturates



Luminosity Integral

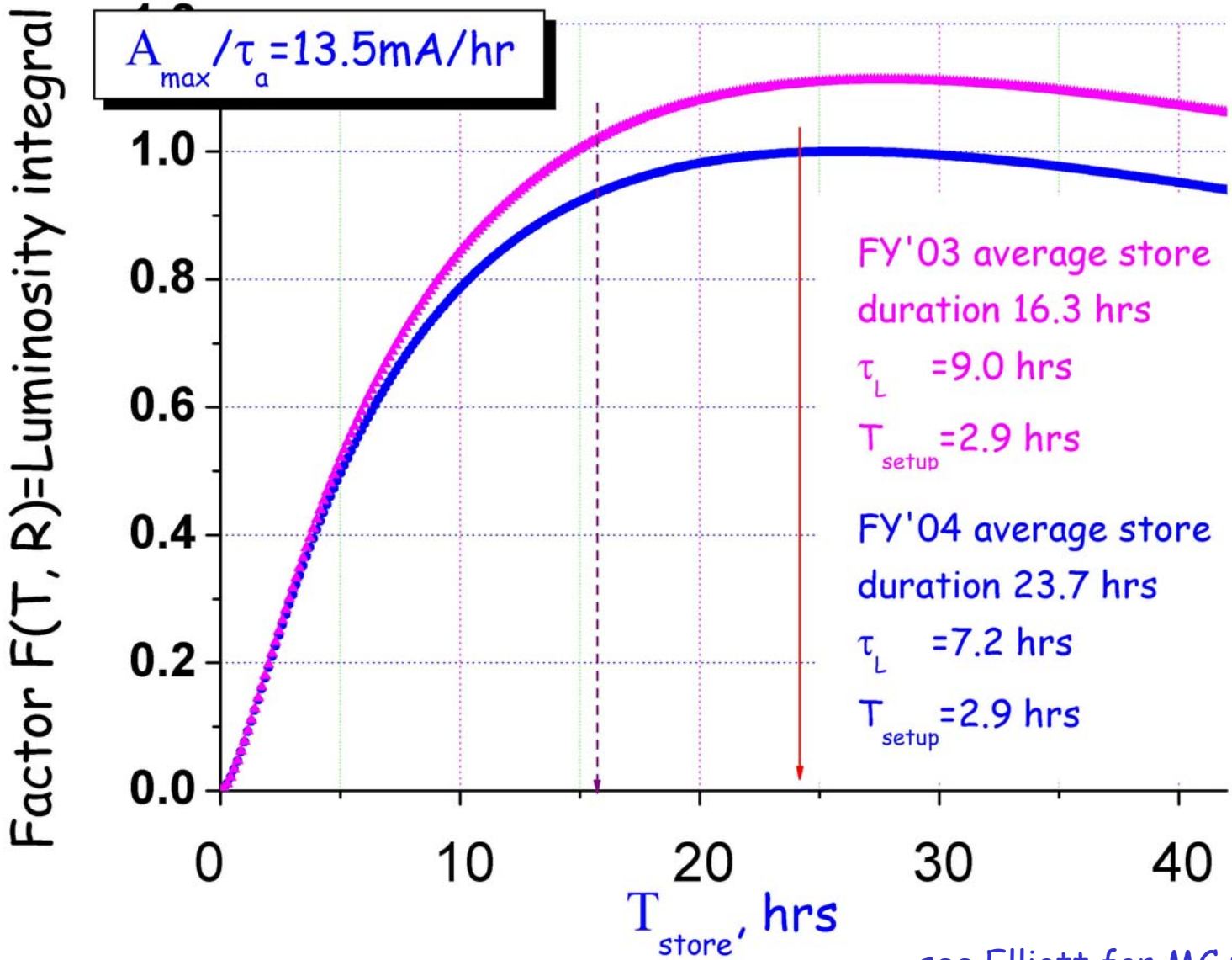
$$I = \int L dt = N_{stores} \tau_L L_0 \ln(1 + T/\tau_L)$$

$$\propto N_{weeks} \eta_{up} \frac{H\left(\frac{\sigma_l}{\beta^*}\right) N_p \eta_a A_{\max}}{\beta^* \left(\varepsilon_p + \varepsilon_{\bar{p}}\right)} F(T, \tau_L, \tau_A, \tau_{SS})$$

$$F = \frac{\tau_L}{T + \tau_{SS}} \ln(1 + T/\tau_L)\left[1 - \exp(-T/\tau_A)\right]$$

see next slide

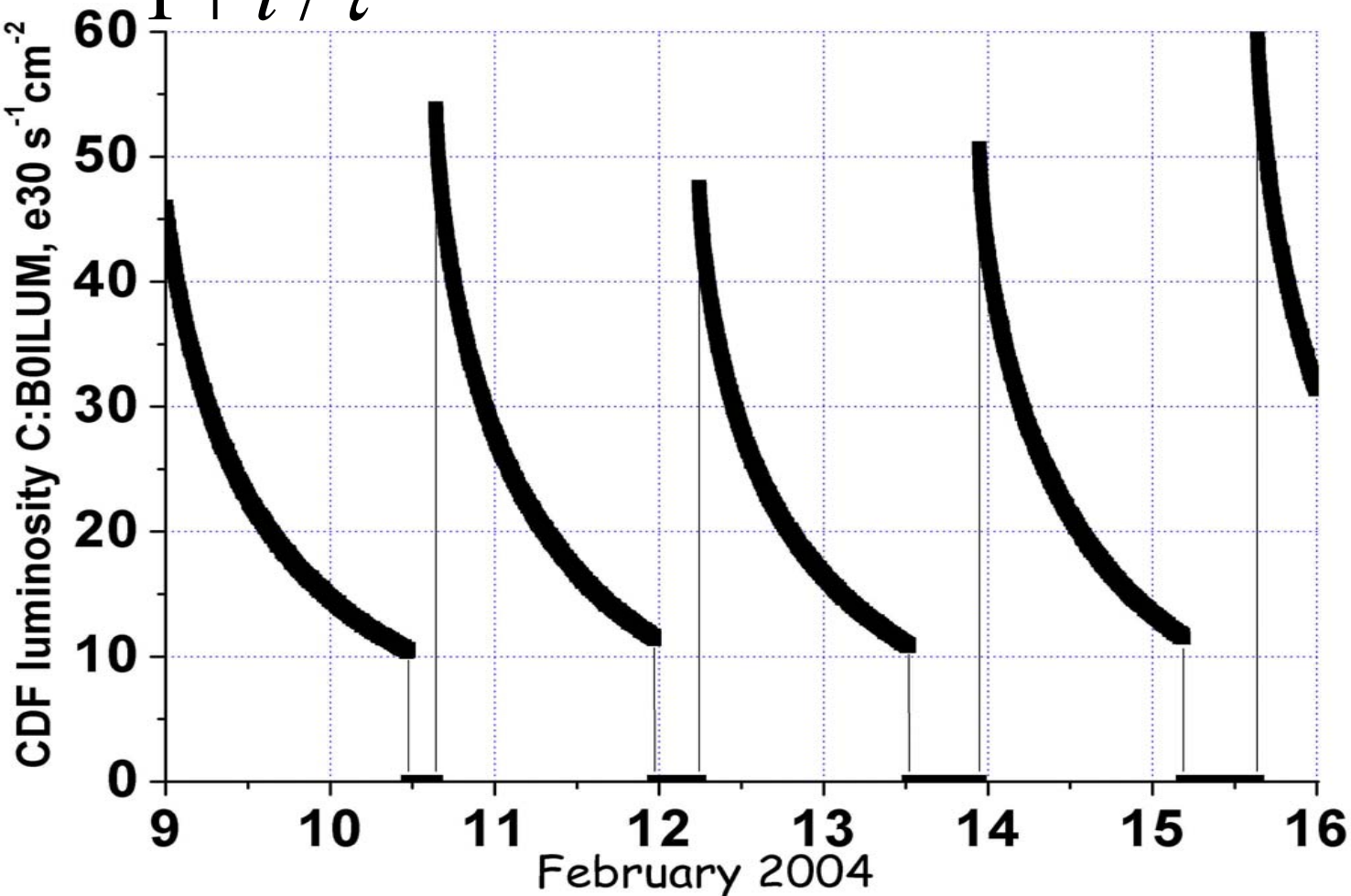
Store Length Optimization Factor *F*



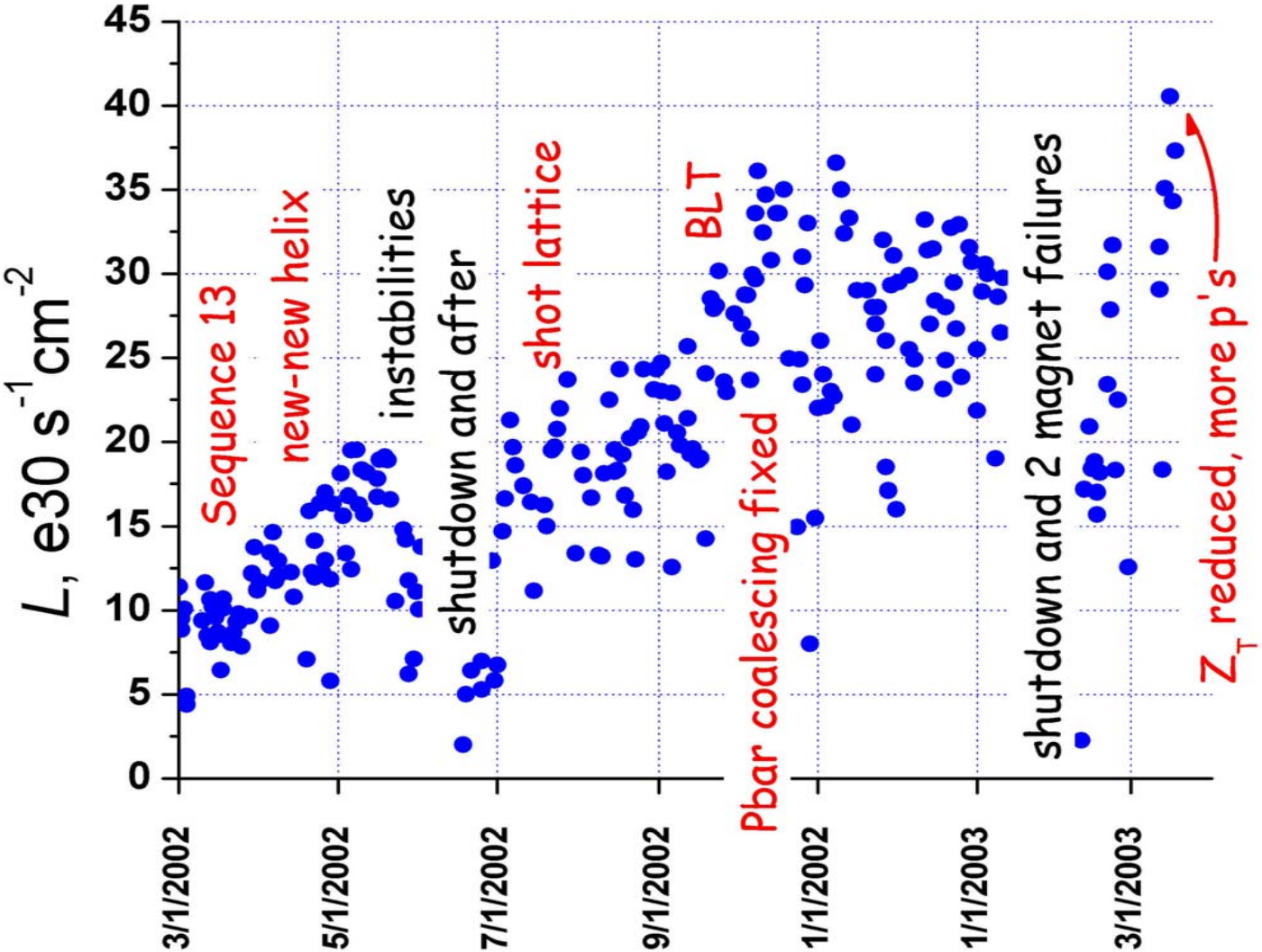
see Elliott for MC model

Integrated Luminosity Factors

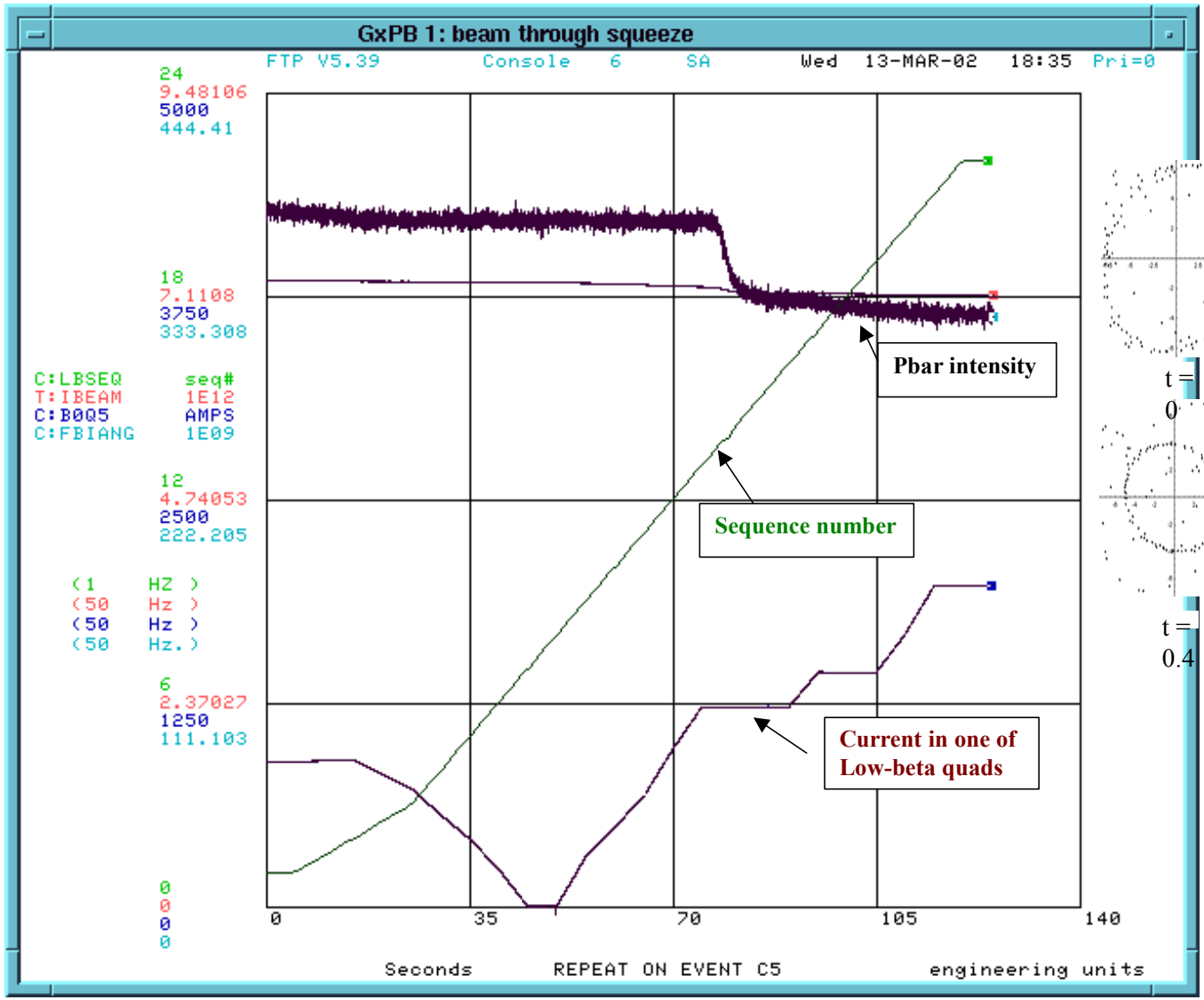
$$I = \int \frac{L_{peak}}{1 + t/\tau} dt \approx L_{peak} \cdot \tau \cdot \ln(1 + T/\tau) \cdot \mathrm{N}_{stores}$$



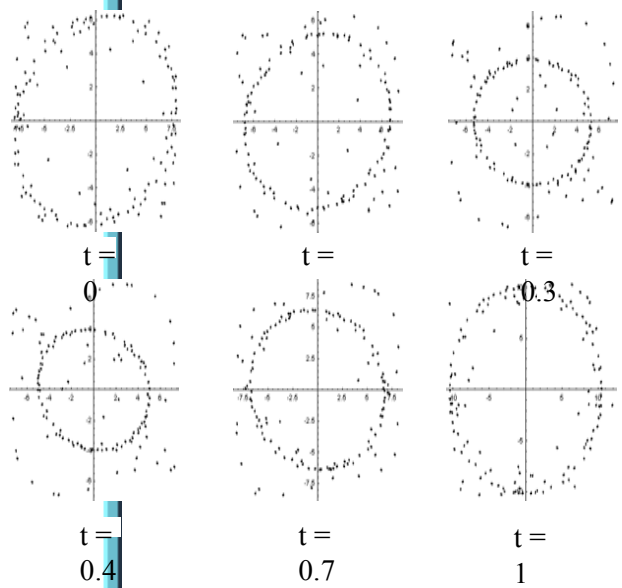
Tevatron 2002-2003



"Sequence 13"



Minimum separation turned out to be only **1.8σ**!



The separation has been increased to 2.7σ and the loss gone

Helix Work: Started in 2002.. Still in progress

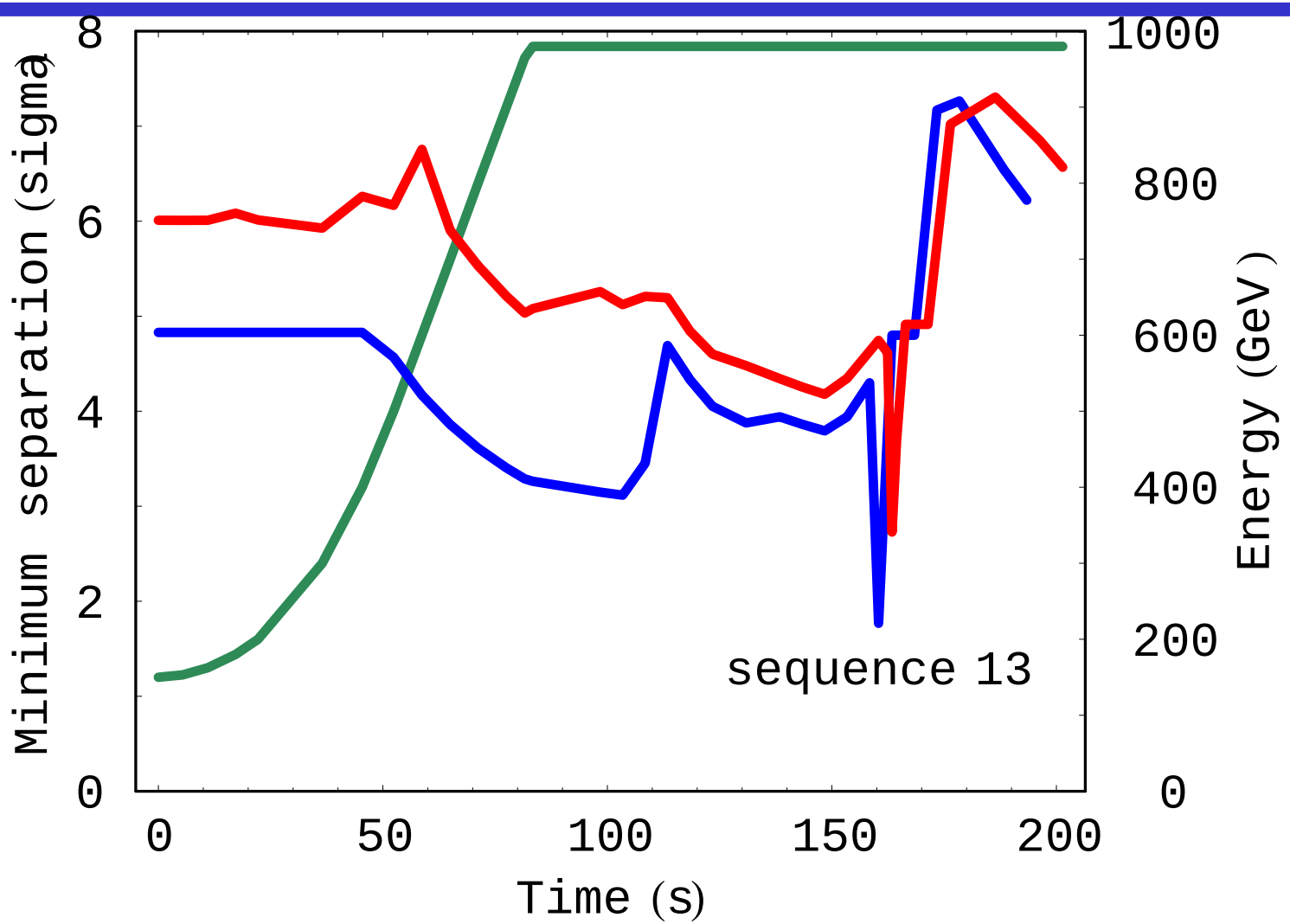
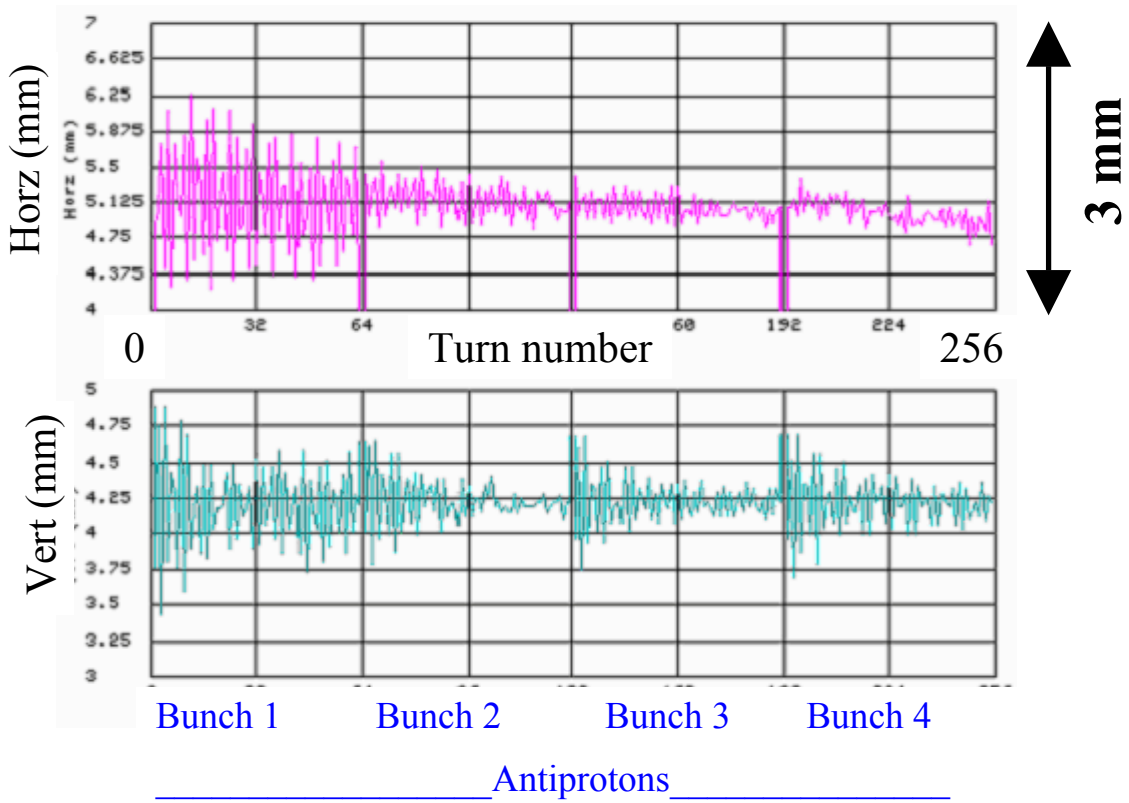


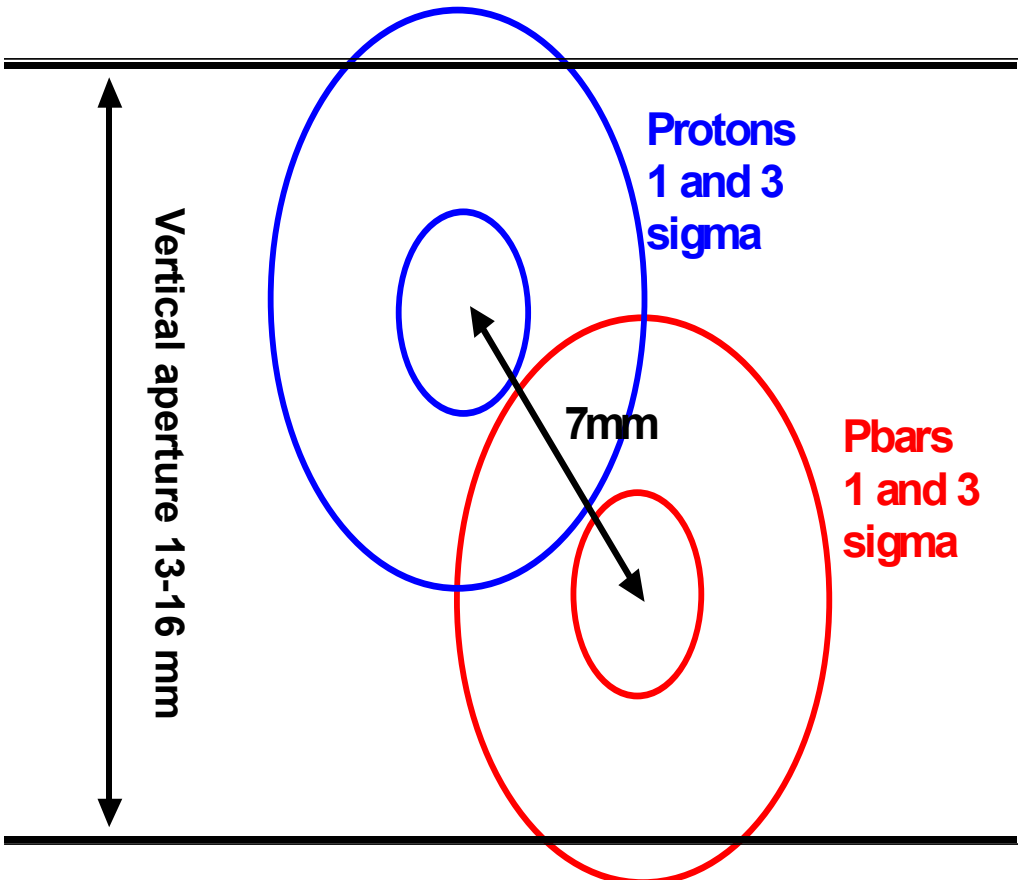
Fig.2.1: Minimum radial separation on ramp and during the low-beta squeeze. Green line – beam energy *E(t)*. Blue and red lines represent *S(t)* circa January 2002 and August 2004, correspondingly.

Injection Oscillations in Tevatron



- Turn-by-turn position monitor, (and bunch-by-bunch for pbar)
- Use to tune up injection closure
- 1 mm corresponds to roughly 3-4π emittance blowup
- ~3-5π pbar emittance blowup eliminated

C0 Lambertson Replacement



Proton and pbar beam position and sizes on the helix at the location of C0 Lambertson

Pbar lifetime depends on emittances and helix size.

C0 Lambertson is severest aperture restriction. (See picture)

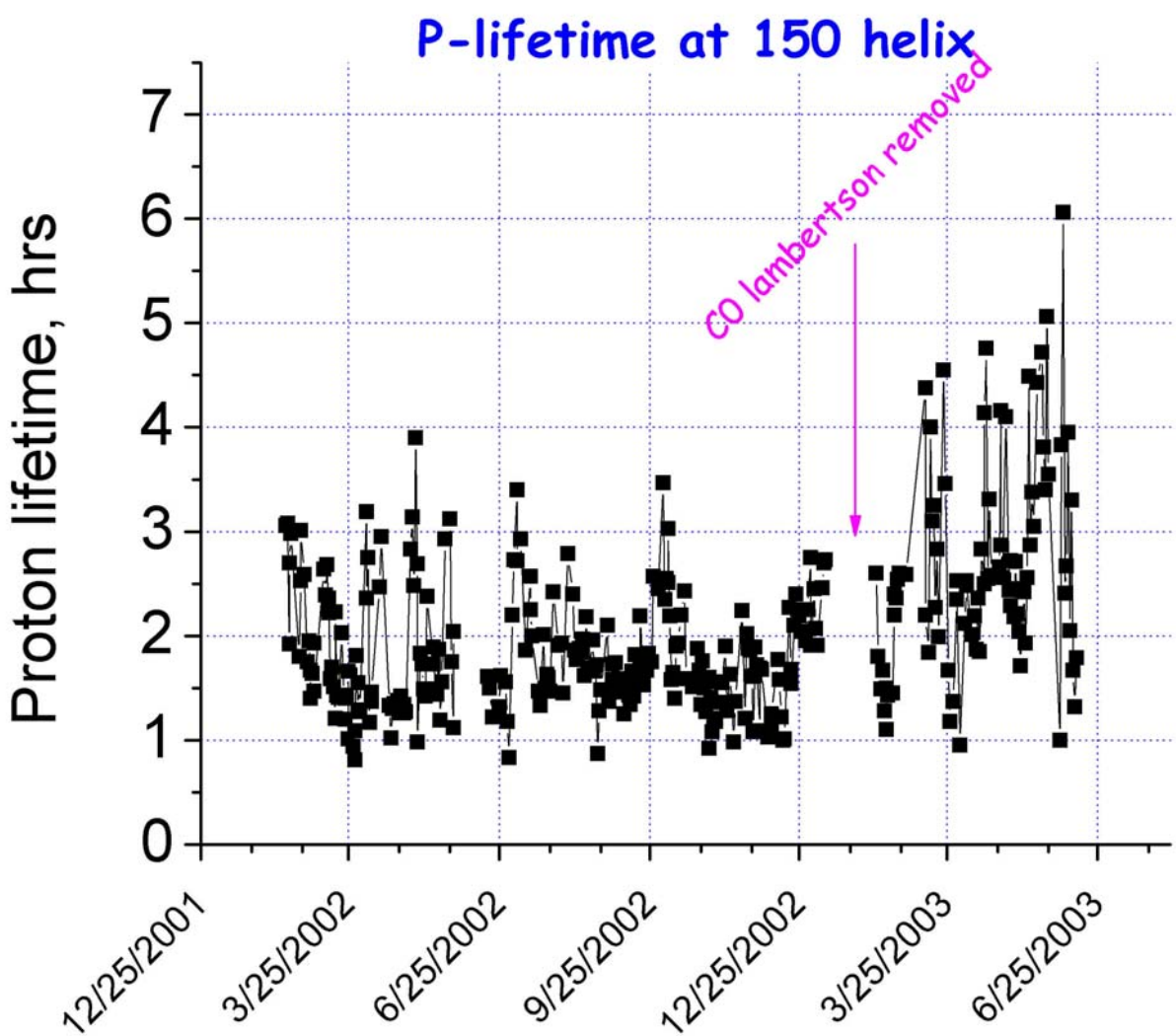
Design injection helix modified and optimized to fit tight C0 aperture ("new-new helix")

(Jan 2003)

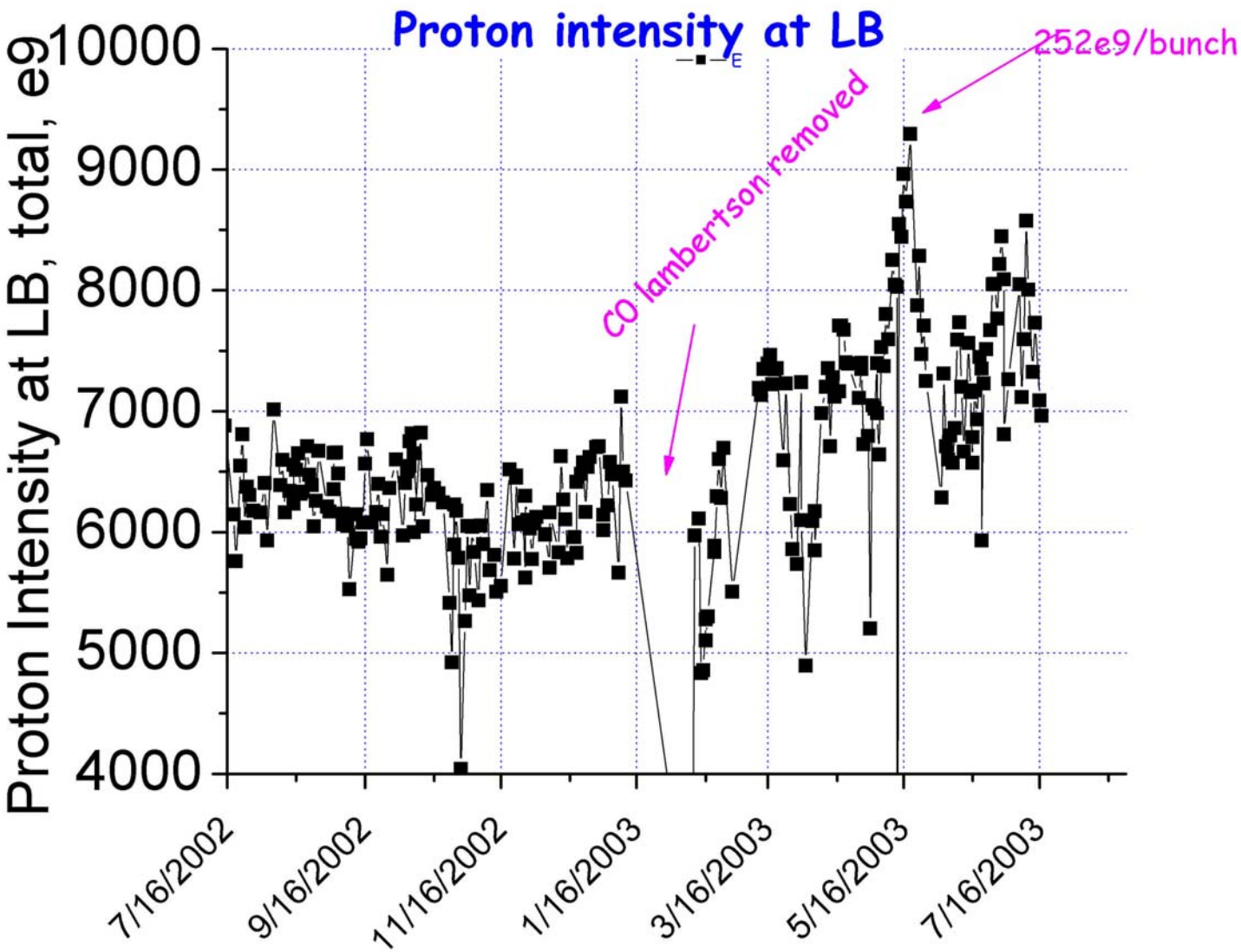
Replace C0 Lambertsons

Gain 25 mm vertically

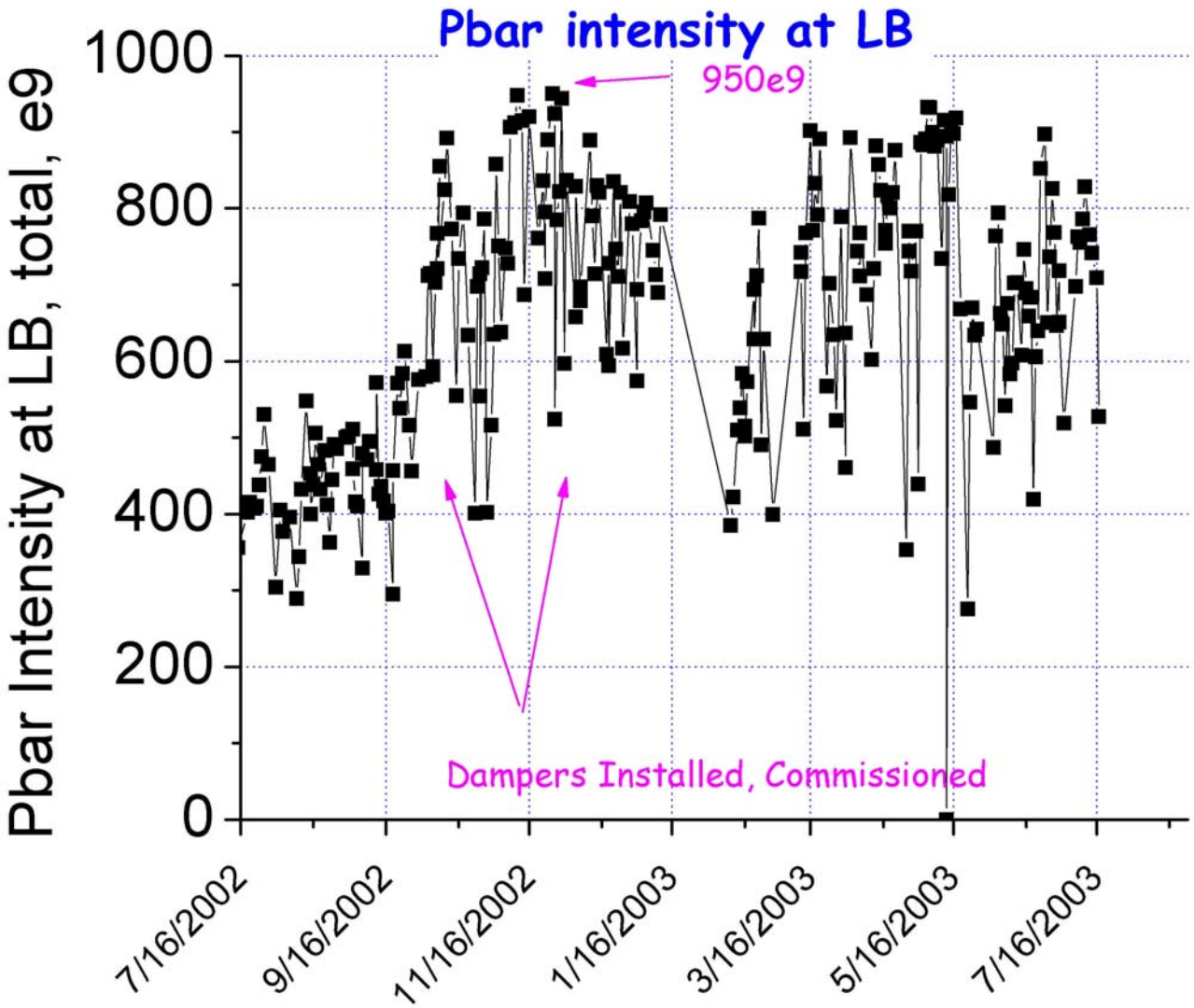
CO Lamberston Removal (Jan'03) – Lifetime improved



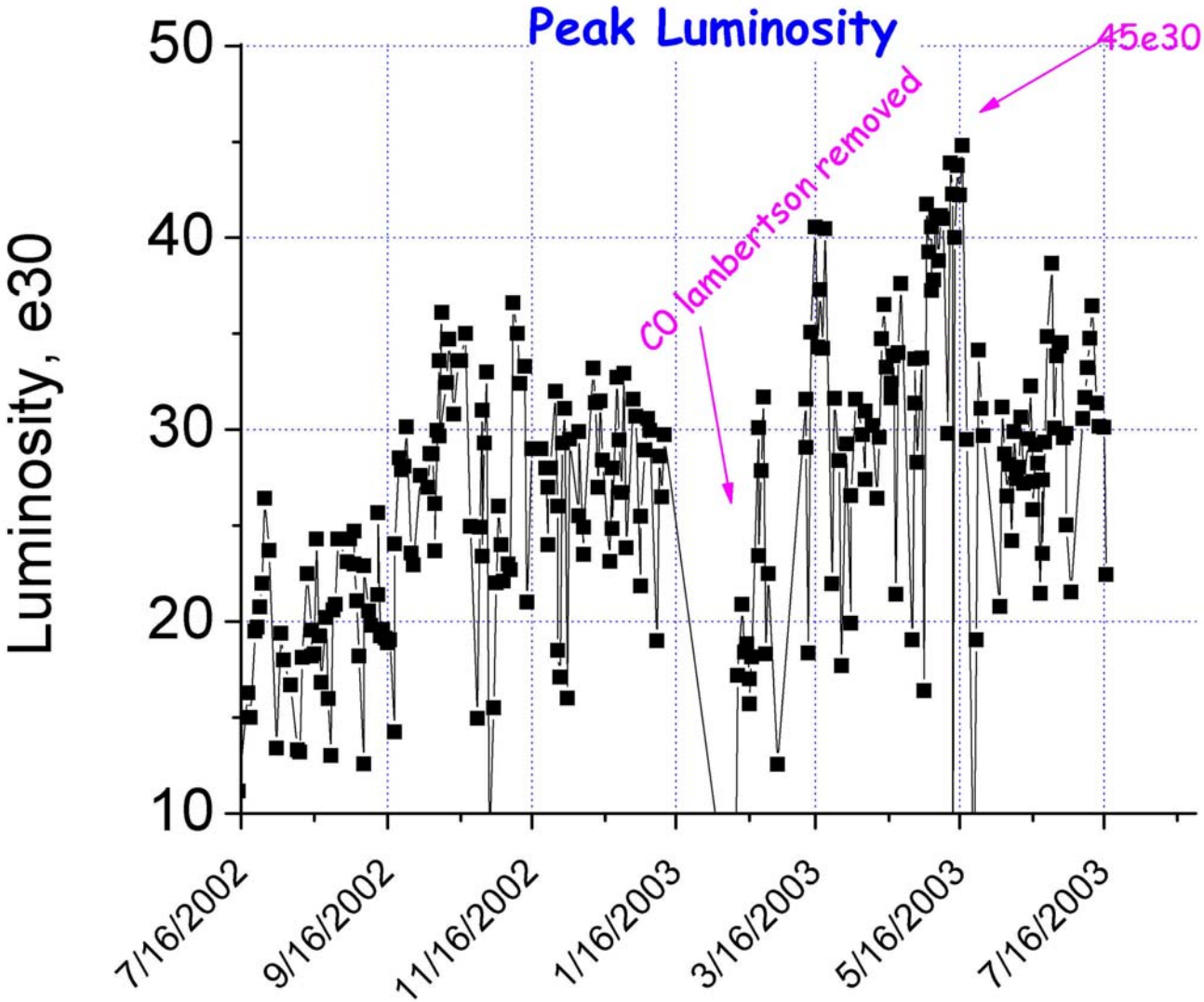
CO Lambertson removed -> p-Intensity Increased



CO Lamberston Removal – No effect on Pbars



Net effect -> Luminosity Increased



$\mathcal{L}$-progress '02 – '03

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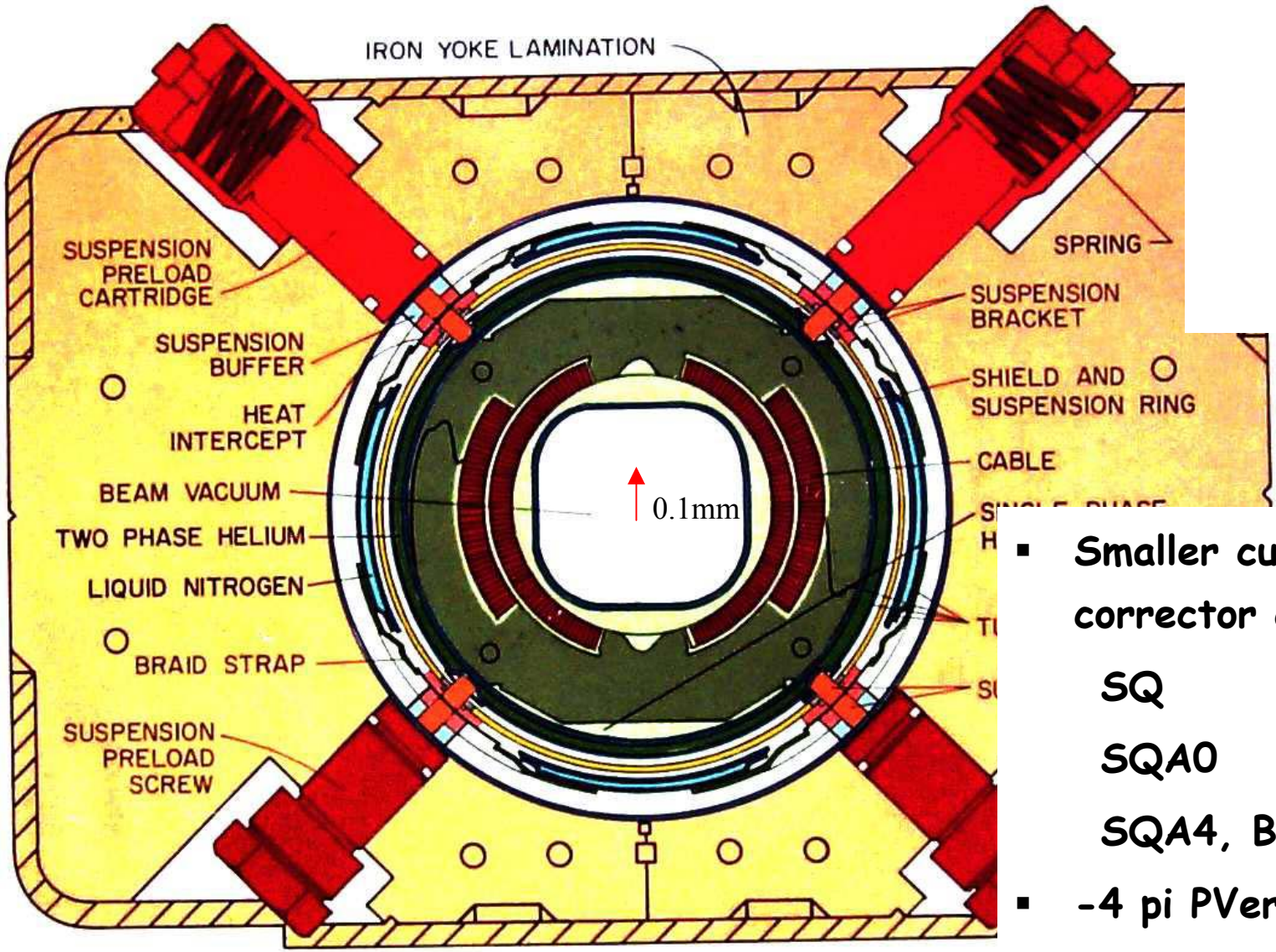
Pbar emittance at injection	Tev/Lines	Fall'02	x 1.20
Pbar coalescing improved	MI	Fall'02	x 1.15
C0 Lambertson removal	Tev	Feb'03	x 1.15

….plus additional improvements in the Tevatron:

- Tunes/coupling/chromaticities at 150/ramp/LB
- Orbit smoothing
- Longitudinal damper to stop σ_s blowup
- Transverse dampers improve 150 Gev lifetime
- Separator scans

Reshimming Tevatron Dipoles



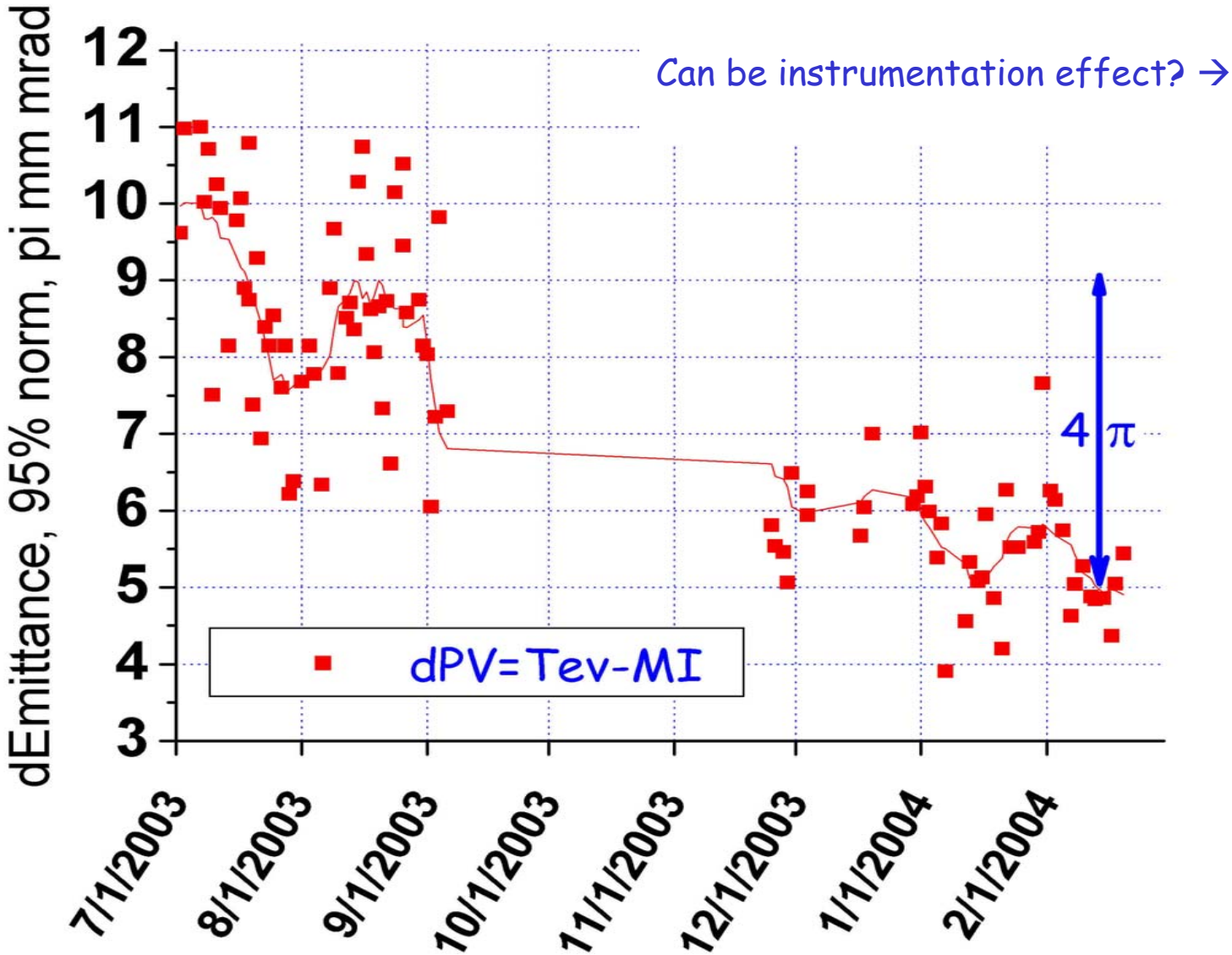
M.Syphers

D.Harding

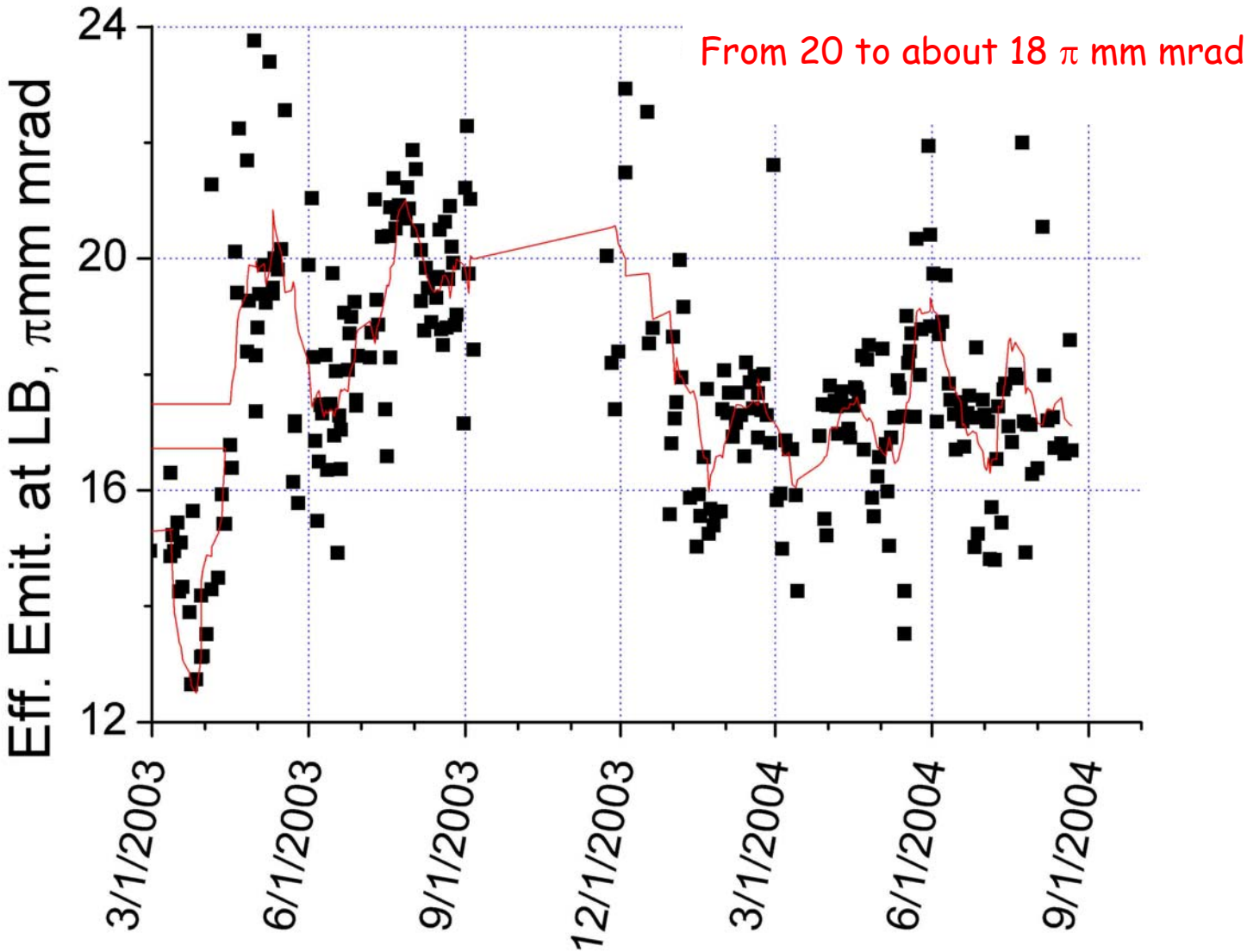
TD team

- Smaller currents in skew corrector circuits:
  - SQ -15%
  - SQA0 -21%
  - SQA4, B1 → 0 A
- -4 pi PVert at Injection

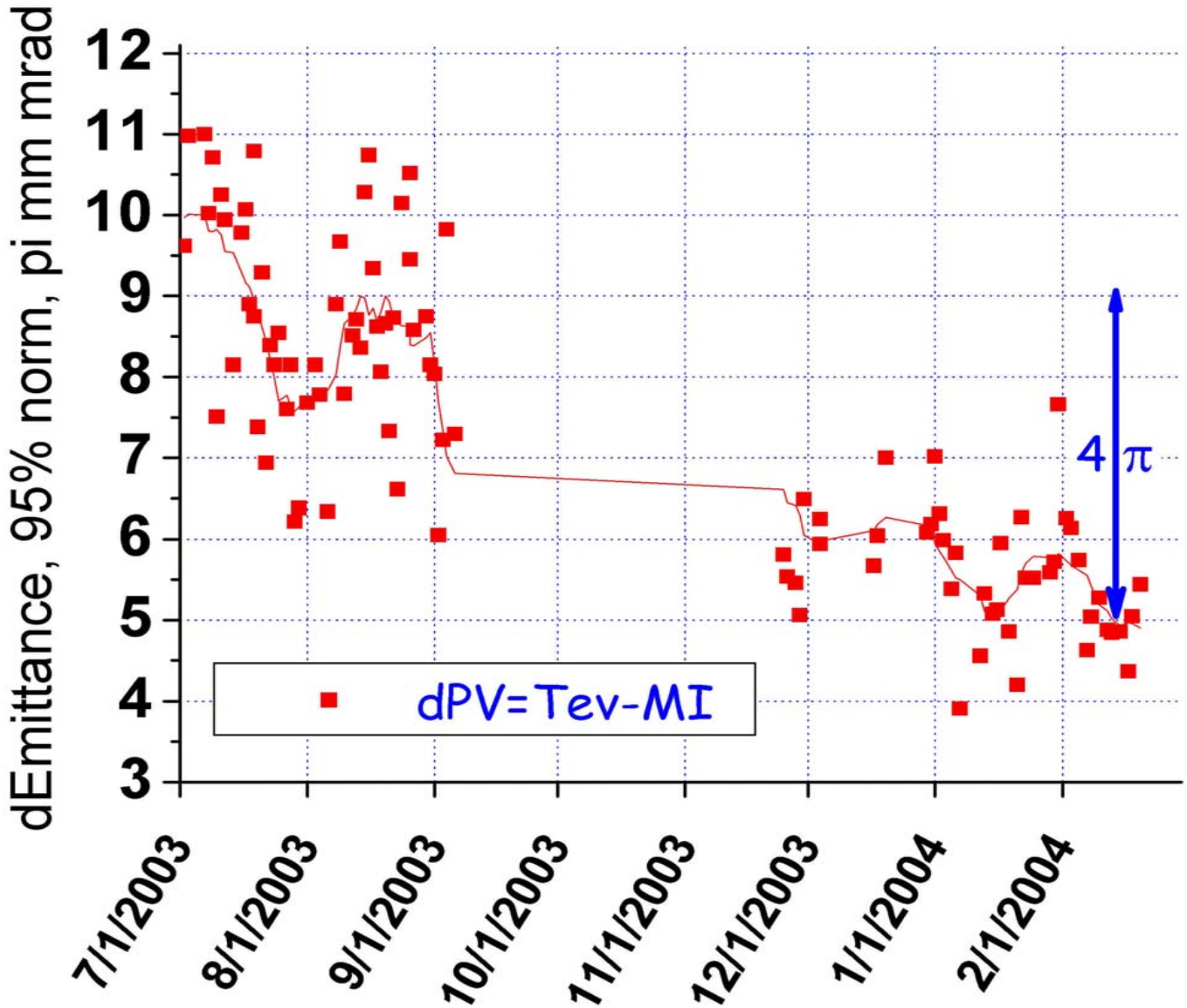
Emittance Dilution in MI→Tev Transfer



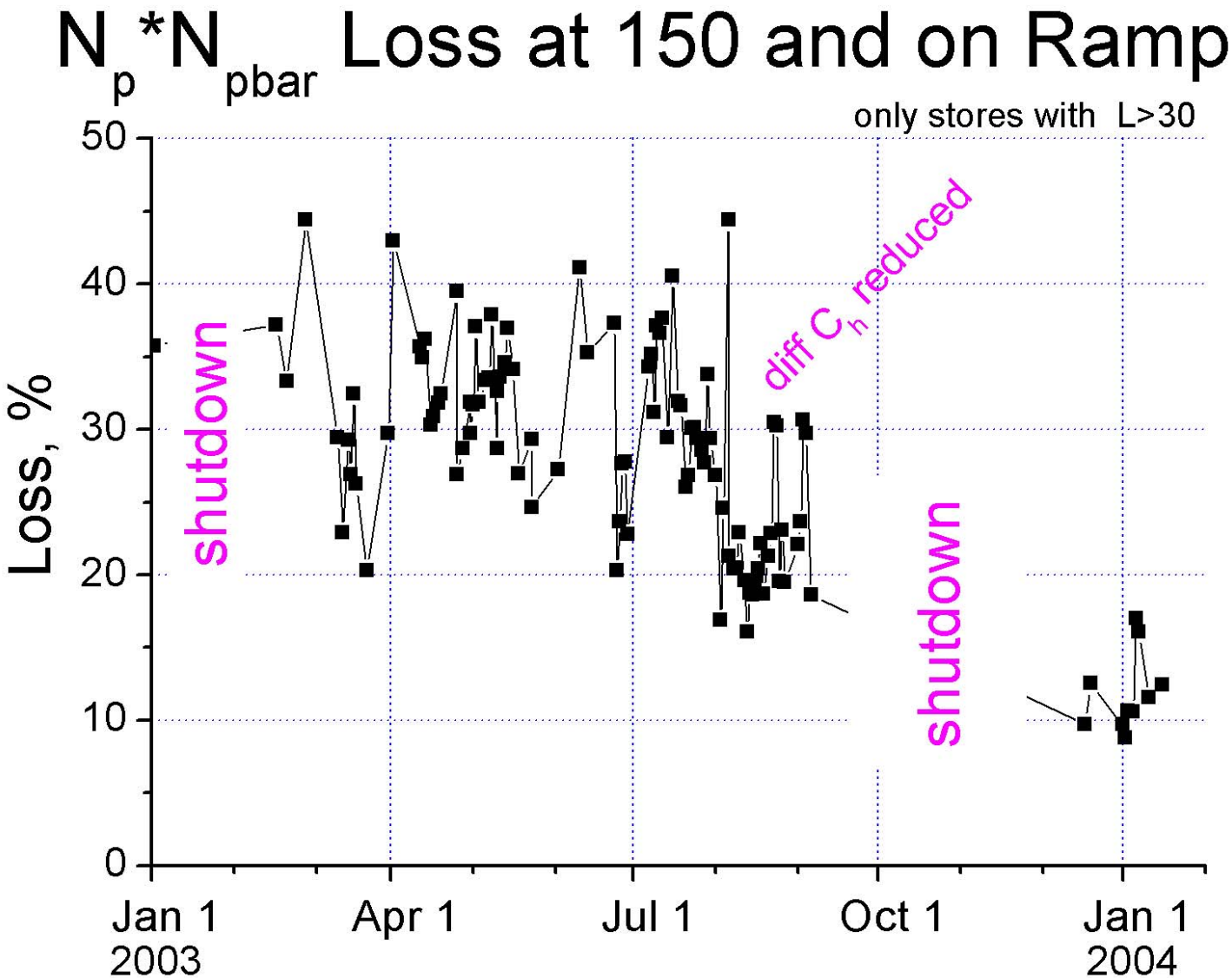
Seen Well in Luminosity



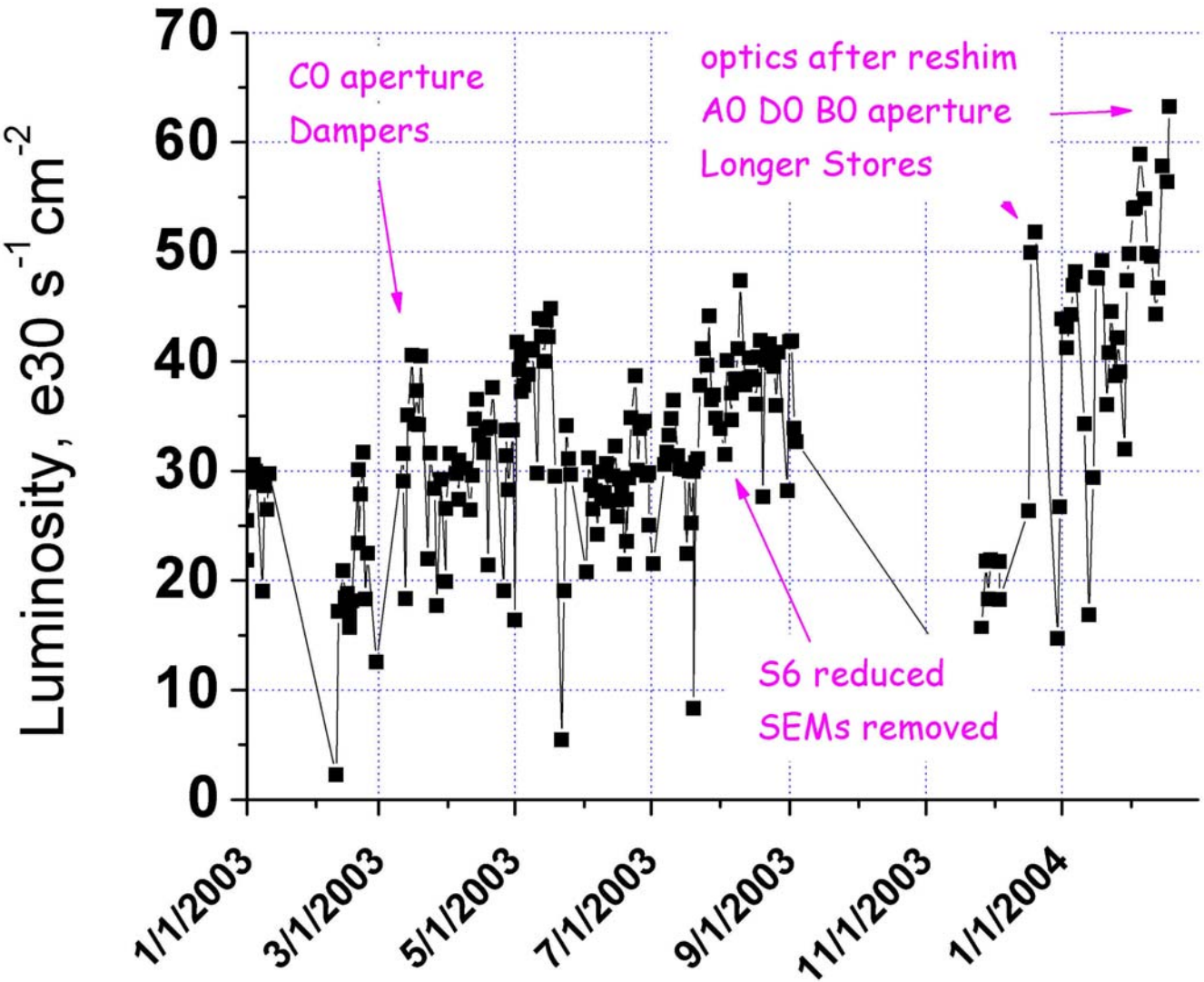
Reduced Emittance Dilution at Injection



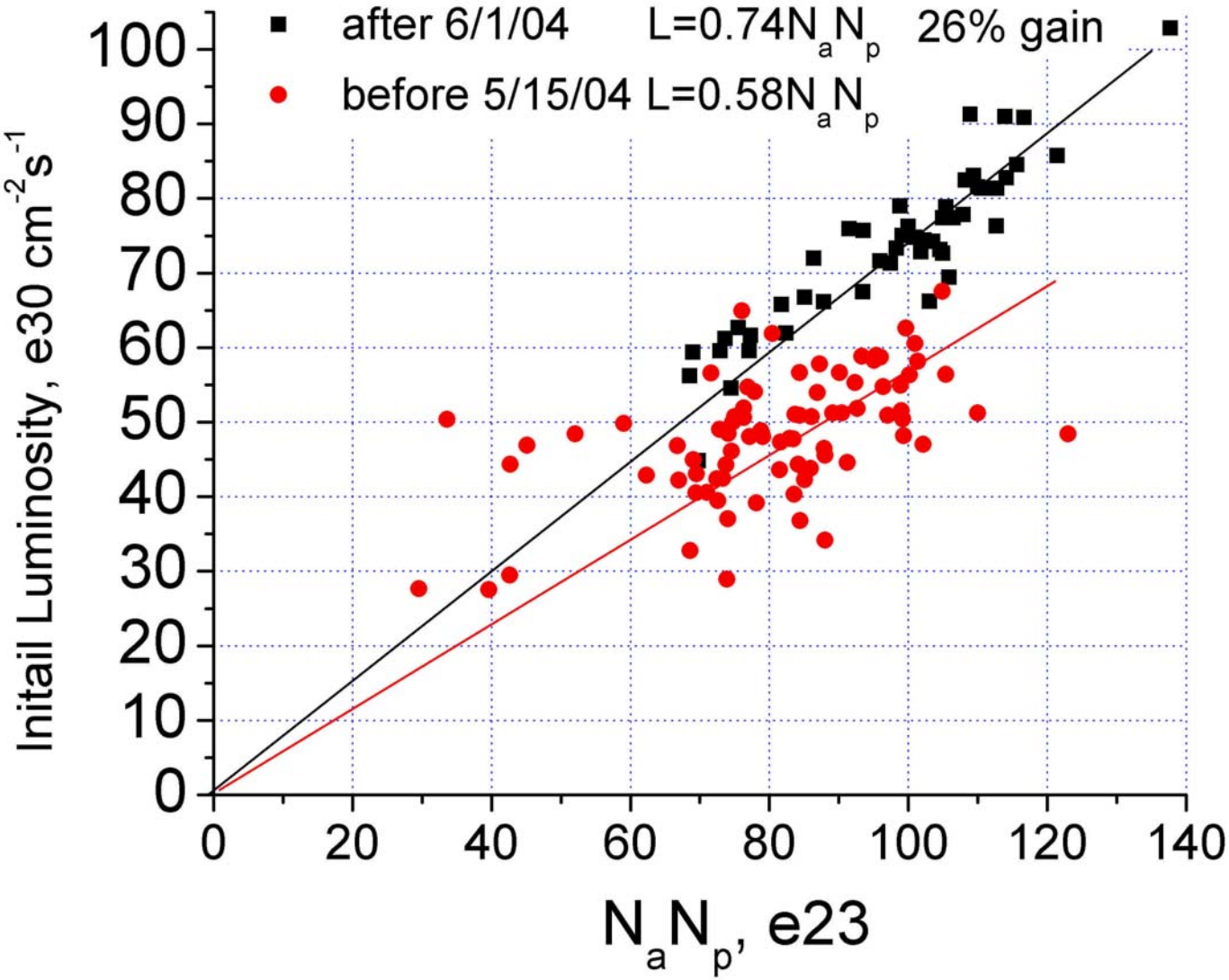
Larger Aperture+Smaller Emm →Better Efficiency



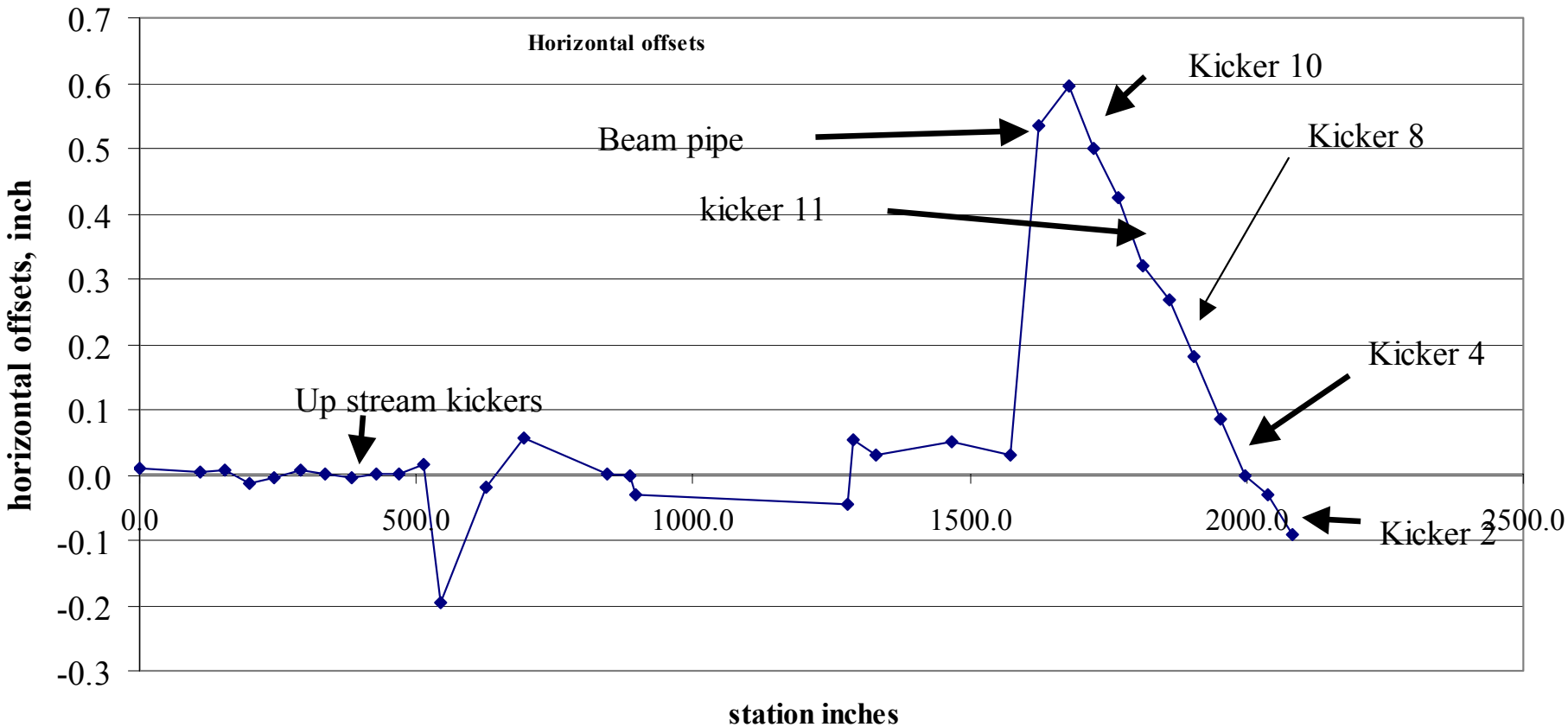
Tevatron Luminosity Progress



…and You Get 26% in Peak Luminosity



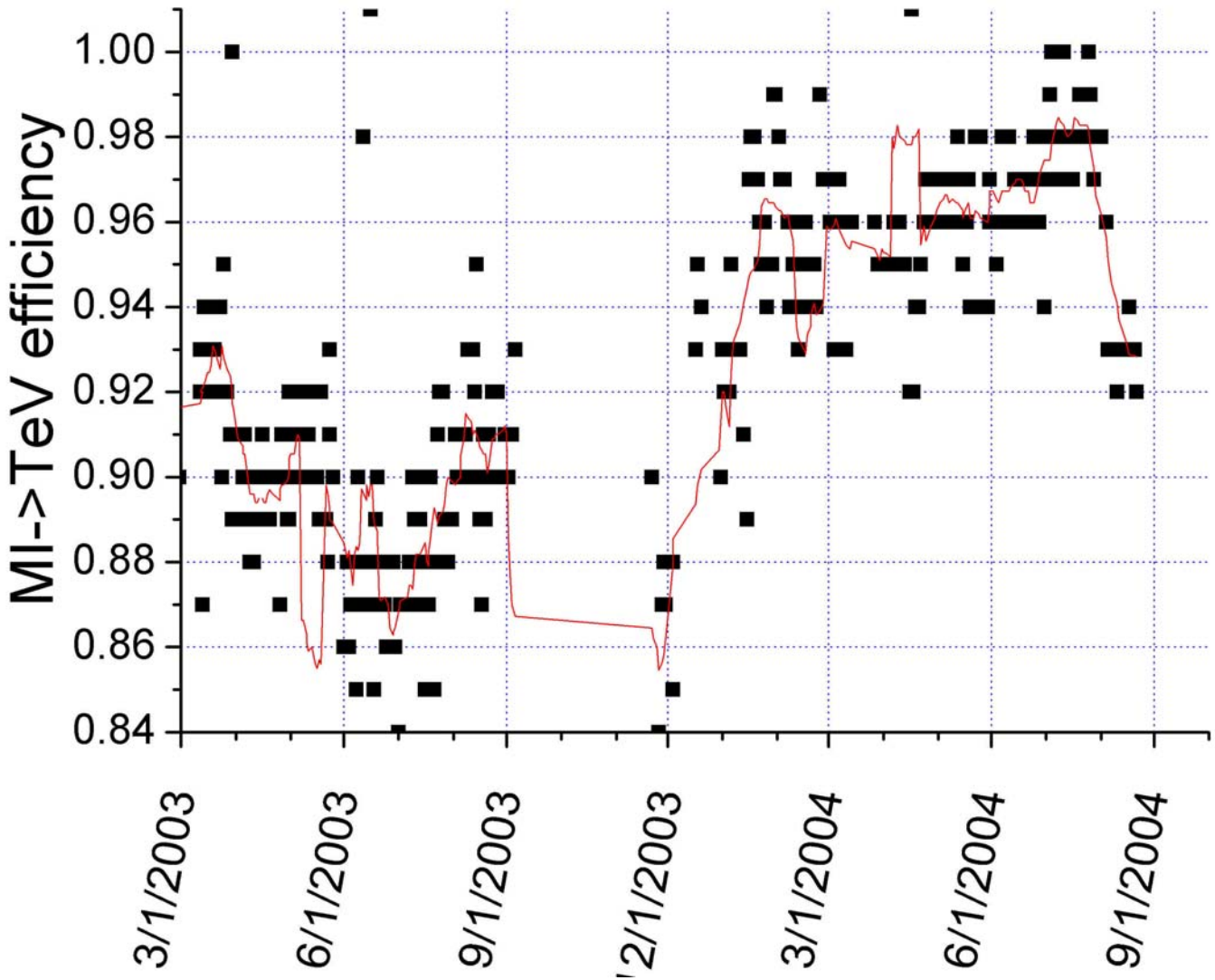
Alignment: Open Apertures



- Another ¼" misalignment fixed at D0
- Rolls >2mrad ~complete
- # of dipole correctors running >35A out of 50A: 26 → 6

Alignment: What it really means…

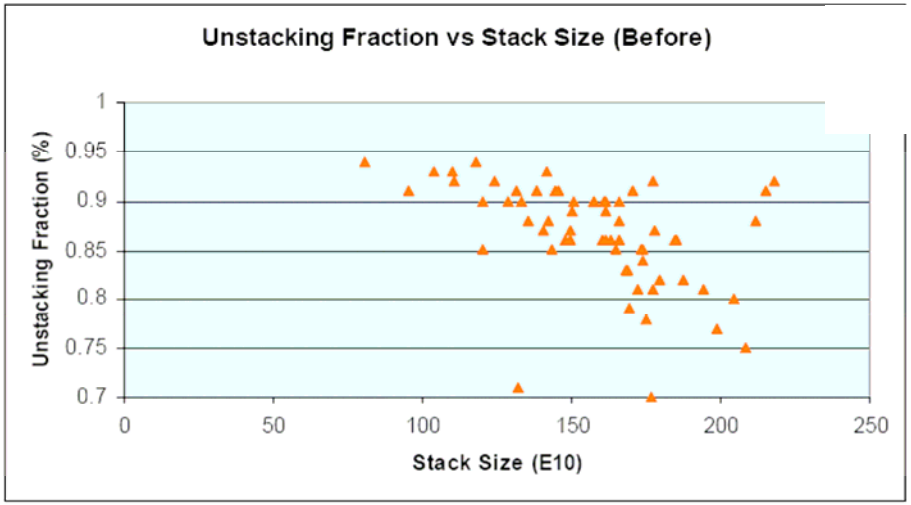
All That Pays Off in Transfer Efficiency

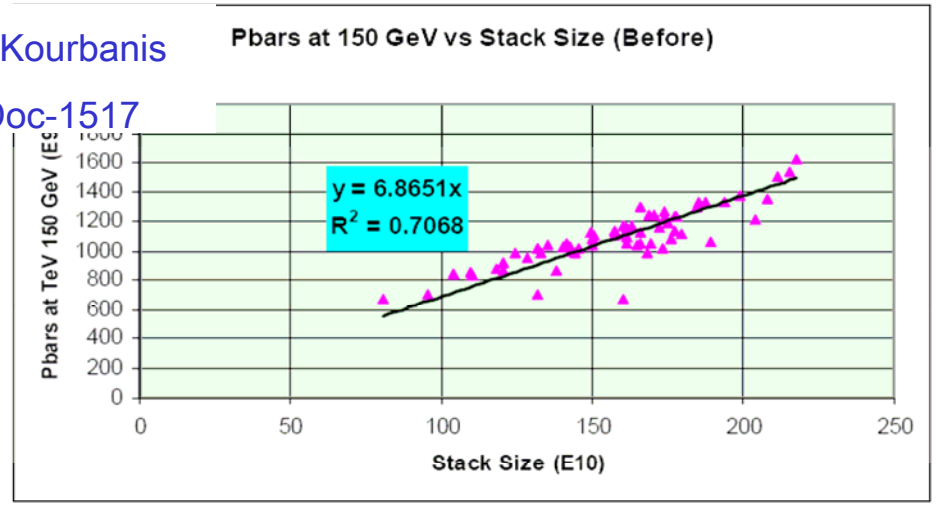


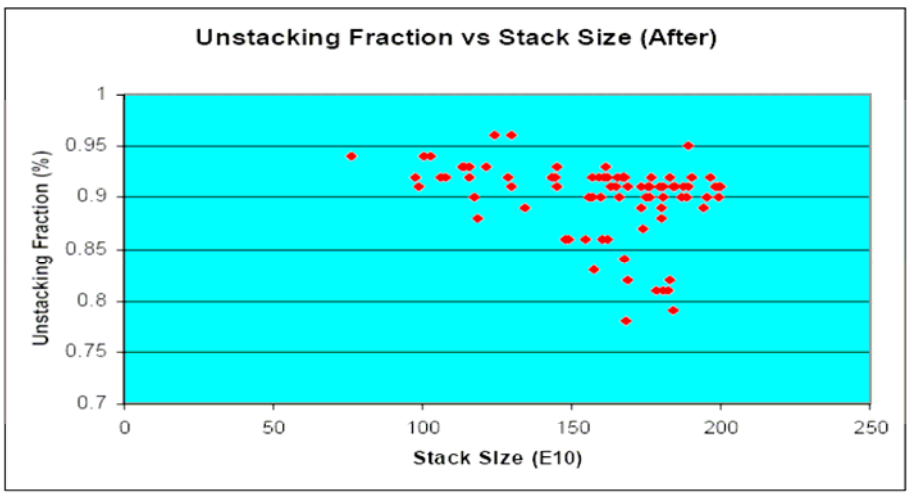
2.5 MHz Transfers: 8% more pbars

I.Kourbanis

Doc-1517







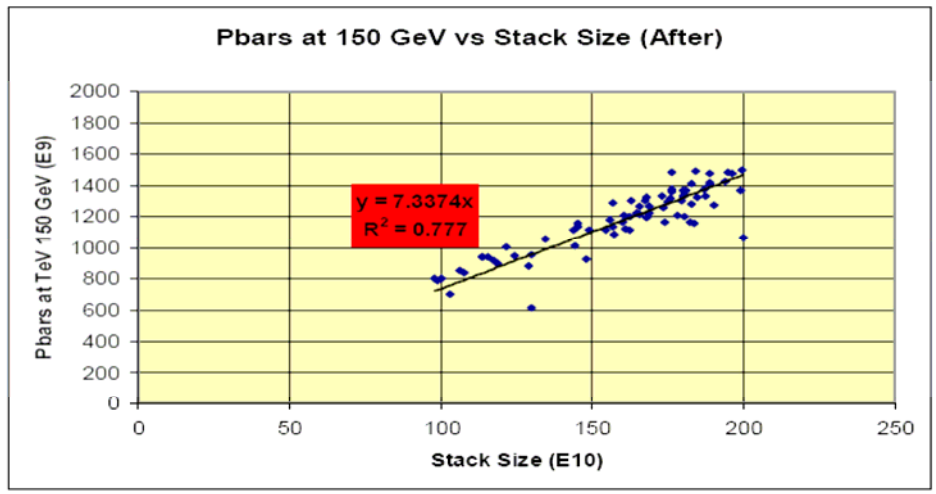
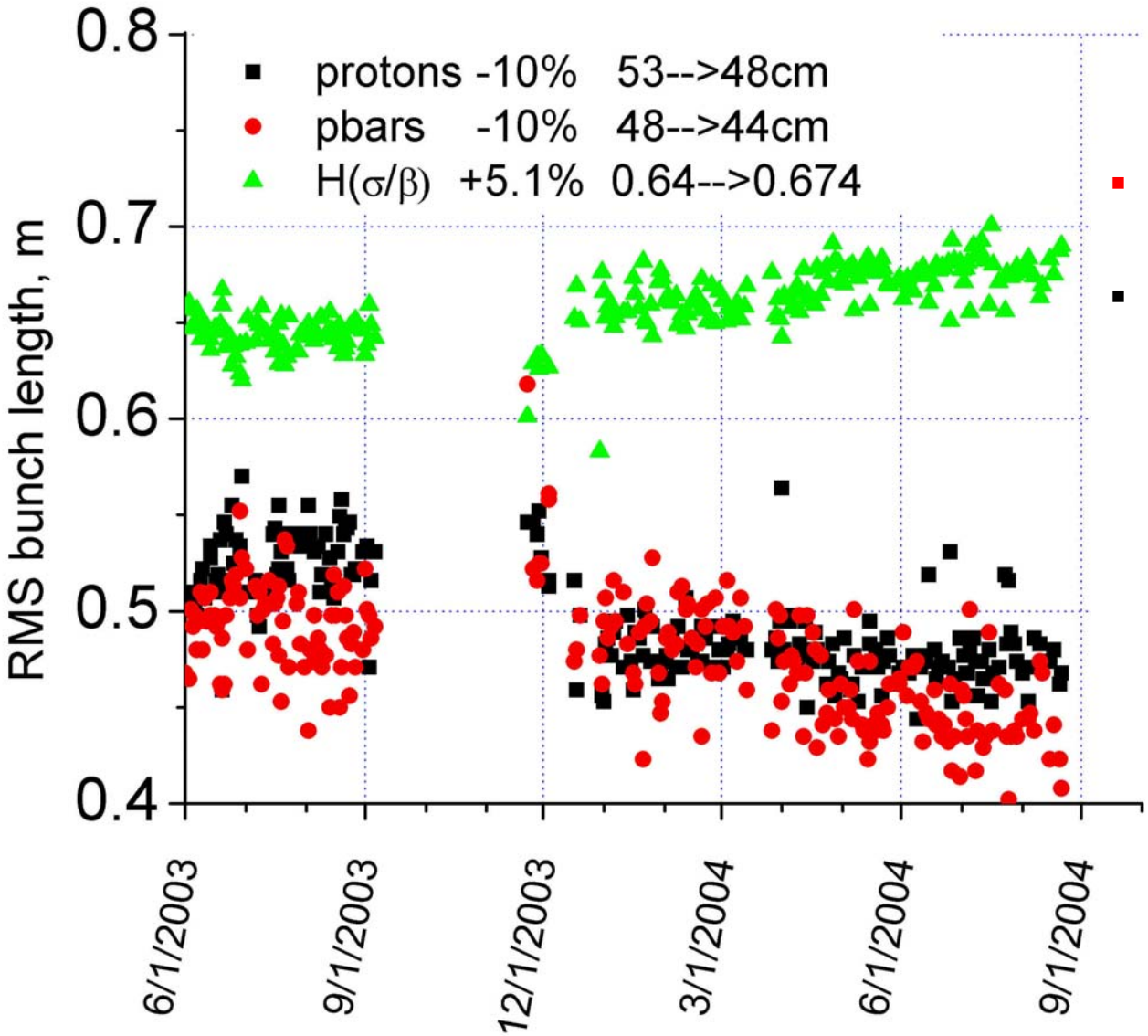


Fig. 5: Unstacking fraction vs. Stack Size for Before the 2.5 MHz pbar Transfers and after

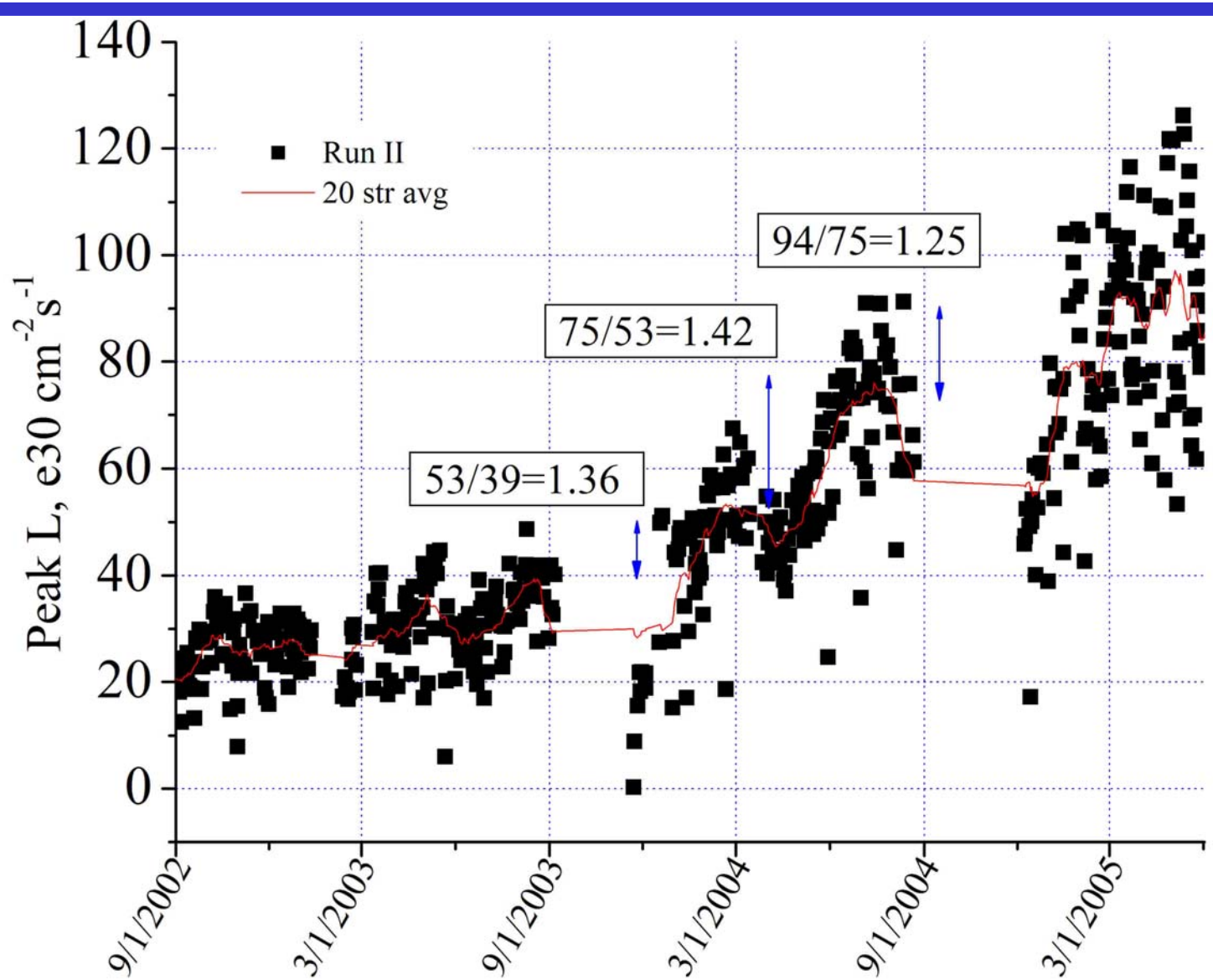
Fig. 6: Pbars at TeV Injection as a function of Pbar Stack Size Before (top) and after (bottom) the 2.5 MHz pbar transfers.

MI Studies Shortens Bunchlength → +5%

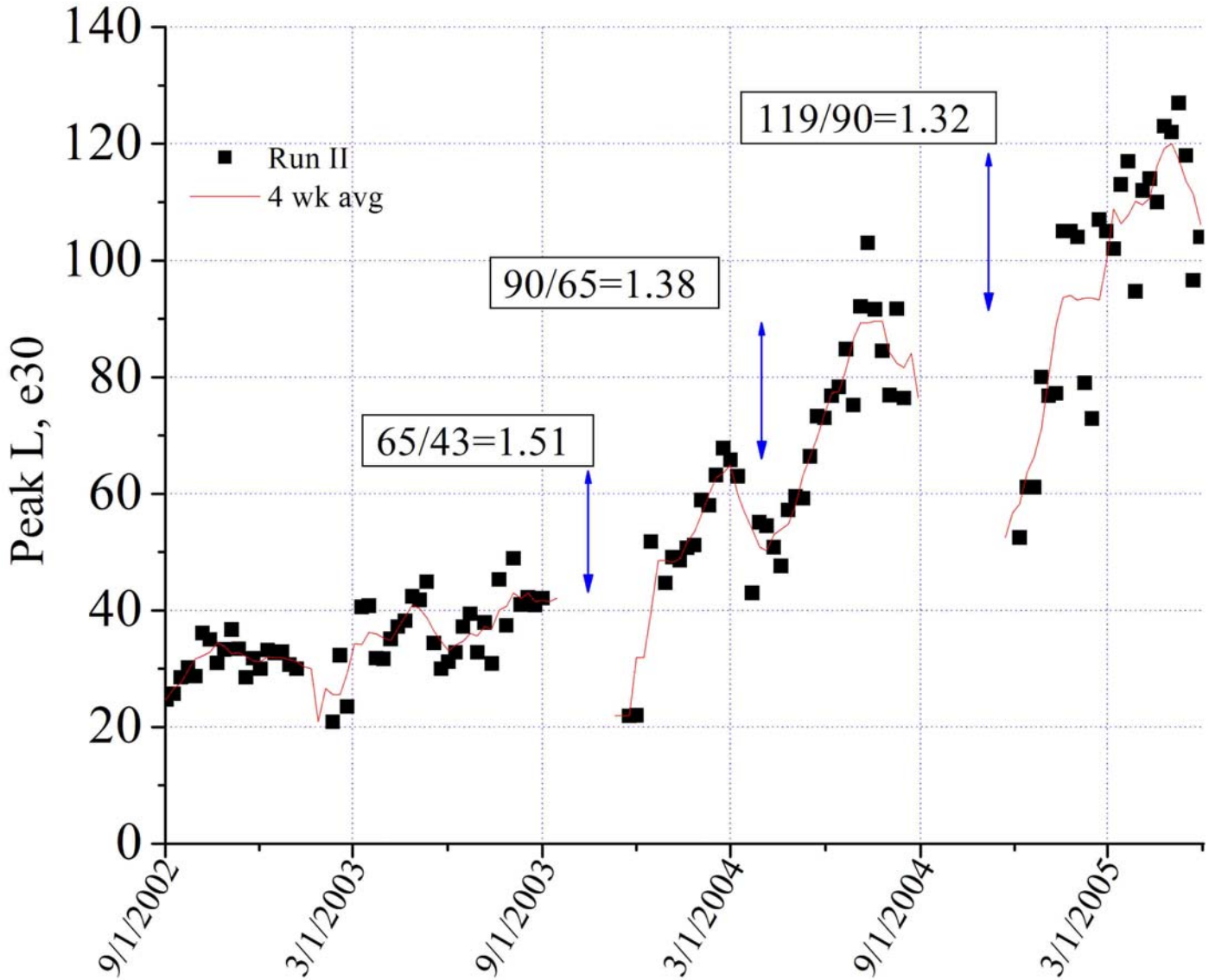


- 2.5 MHz transfers of pbars from AA to MI
- Beam loading compensation and longitudinal instability damper for protons

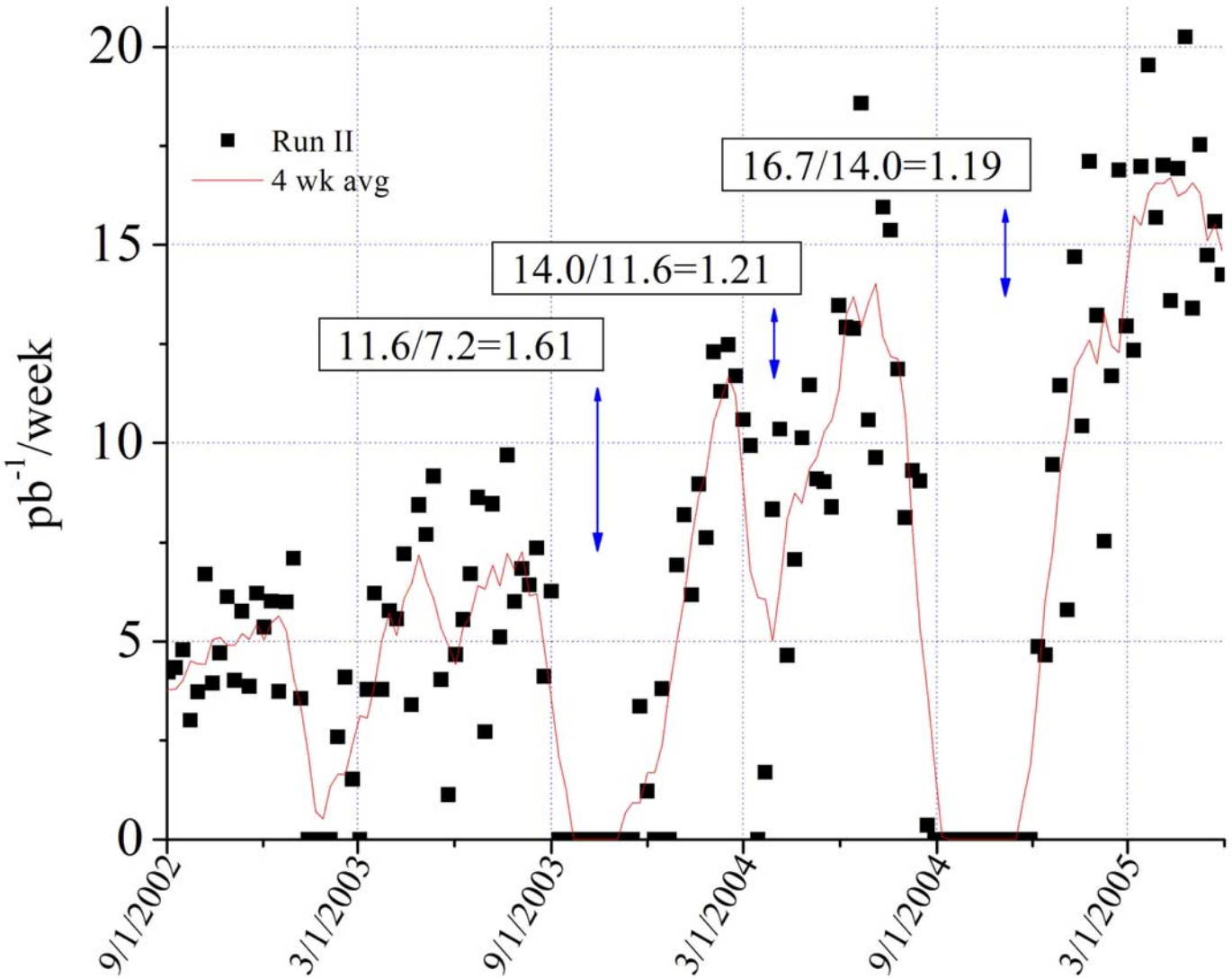
Peak Luminosity progress since 09/2002



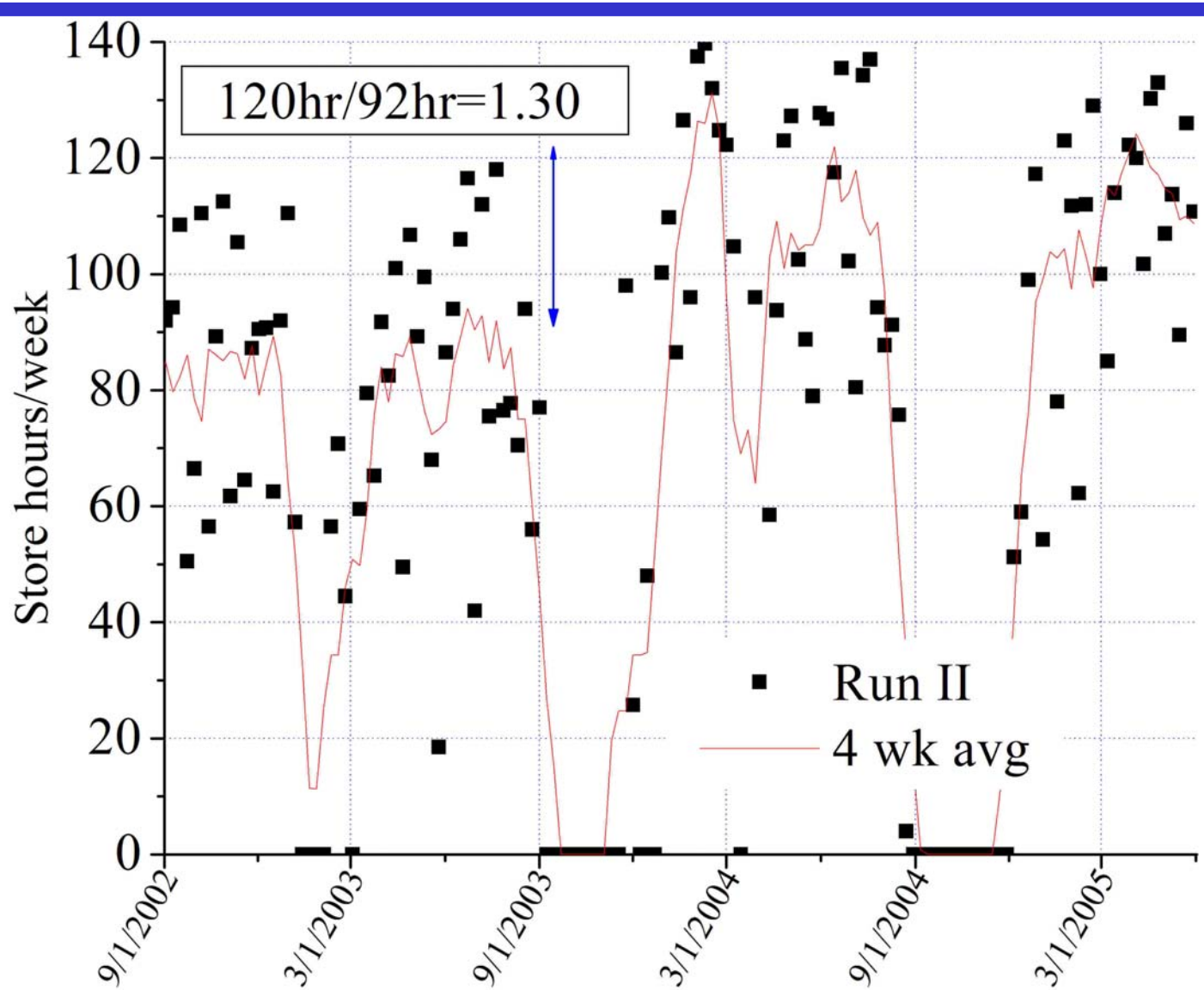
Maximum Peak Luminosity progress since 09/2002



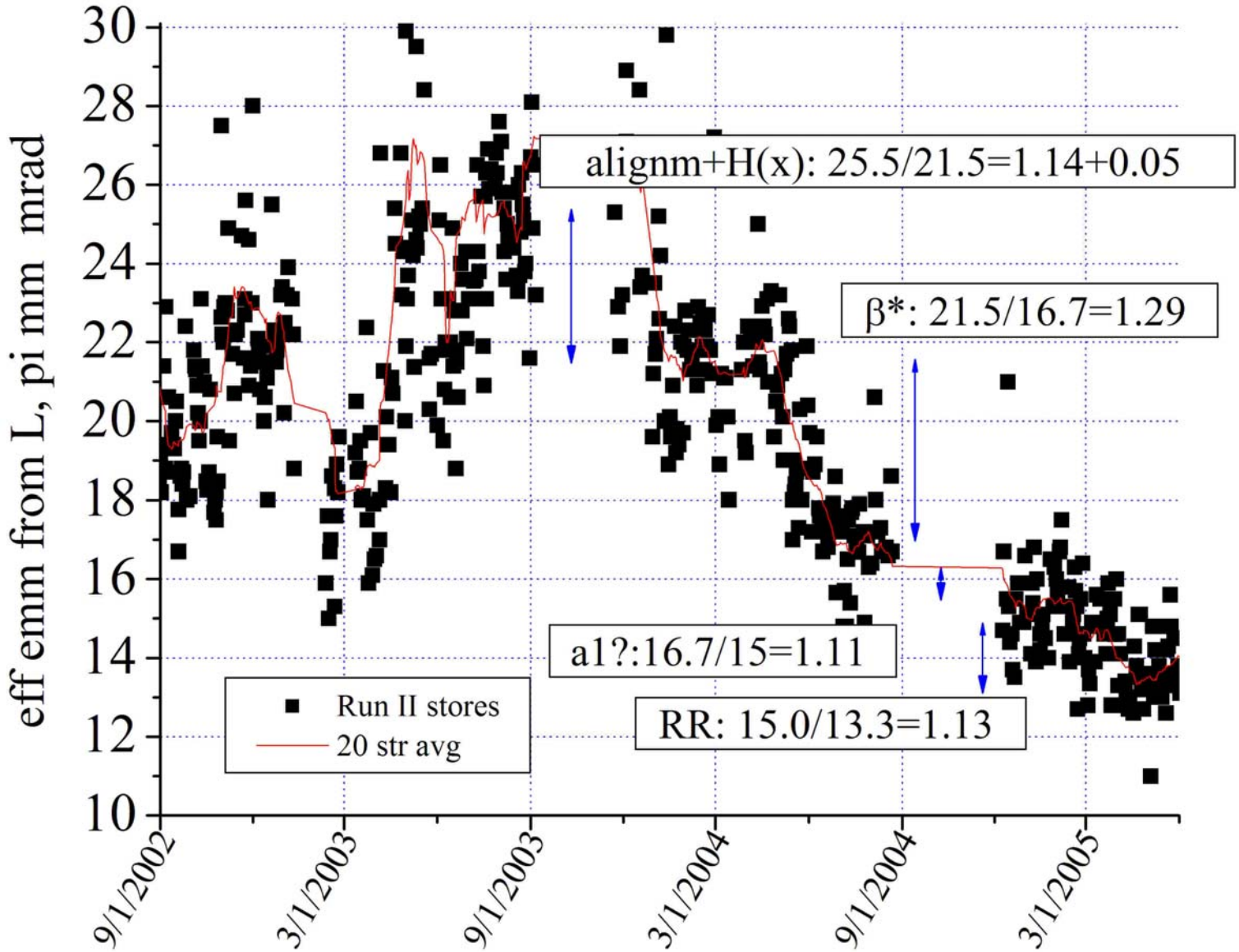
Integrated Luminosity per week



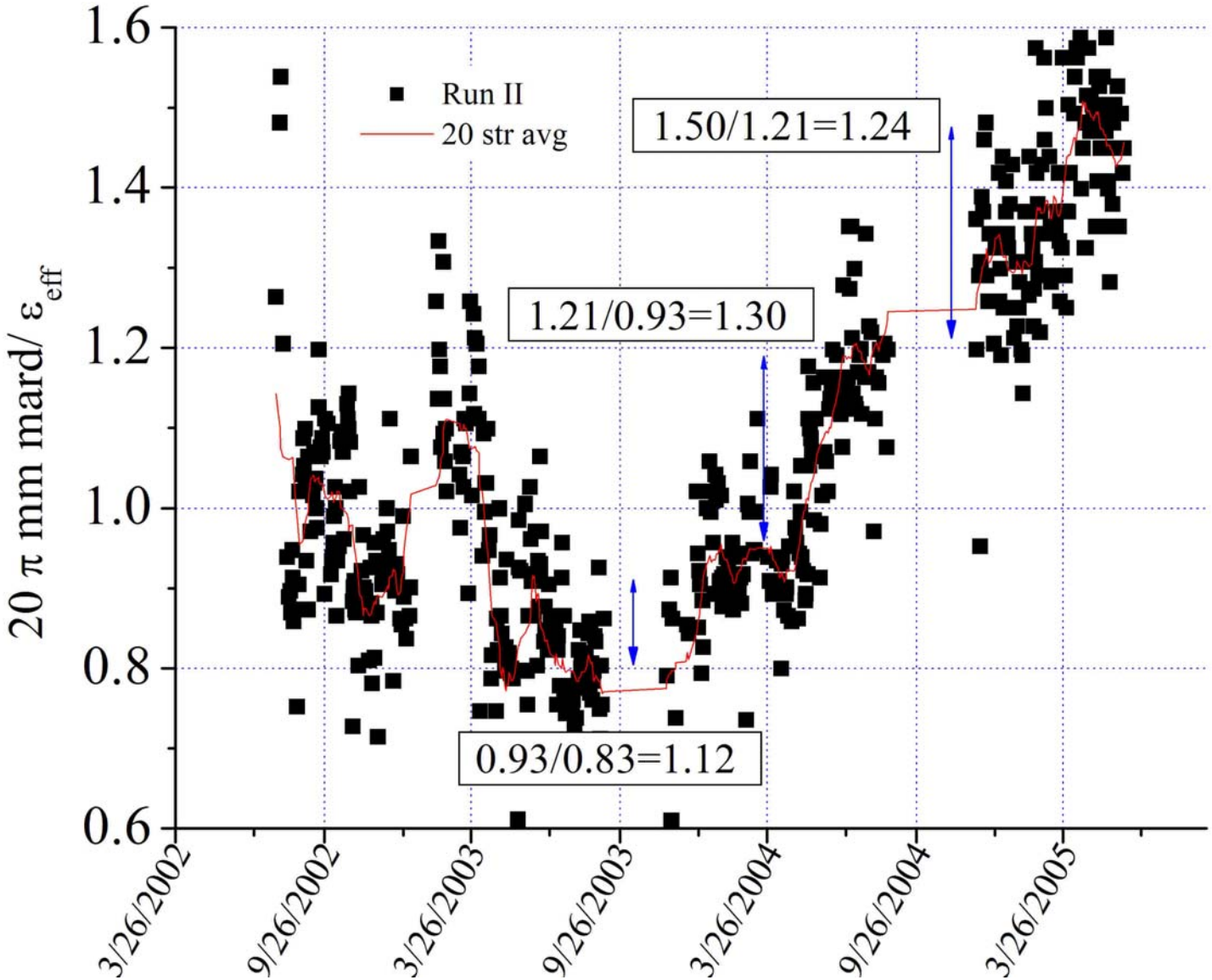
Store Hours/ wk in Run II



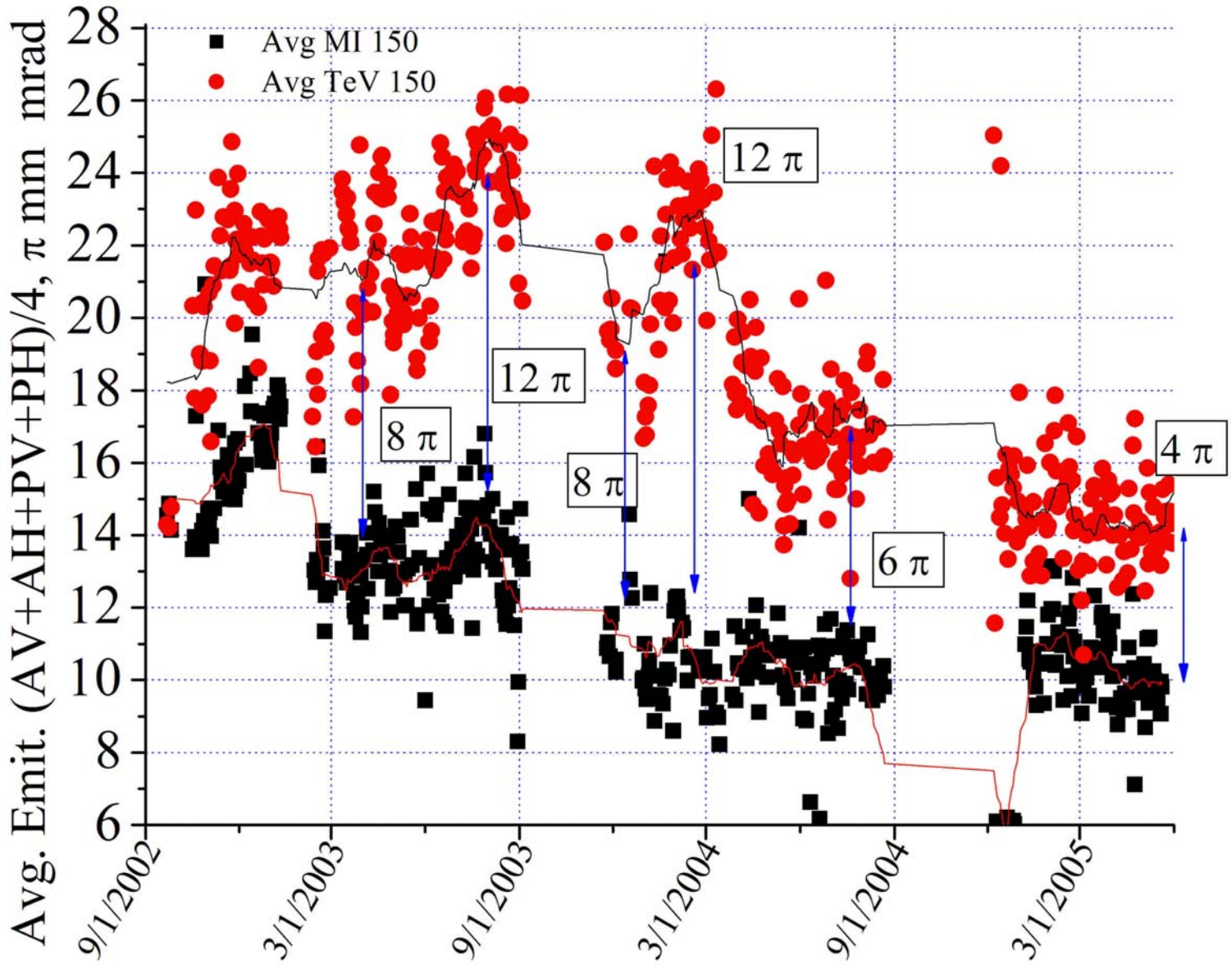
Effective Emittance from Luminosity



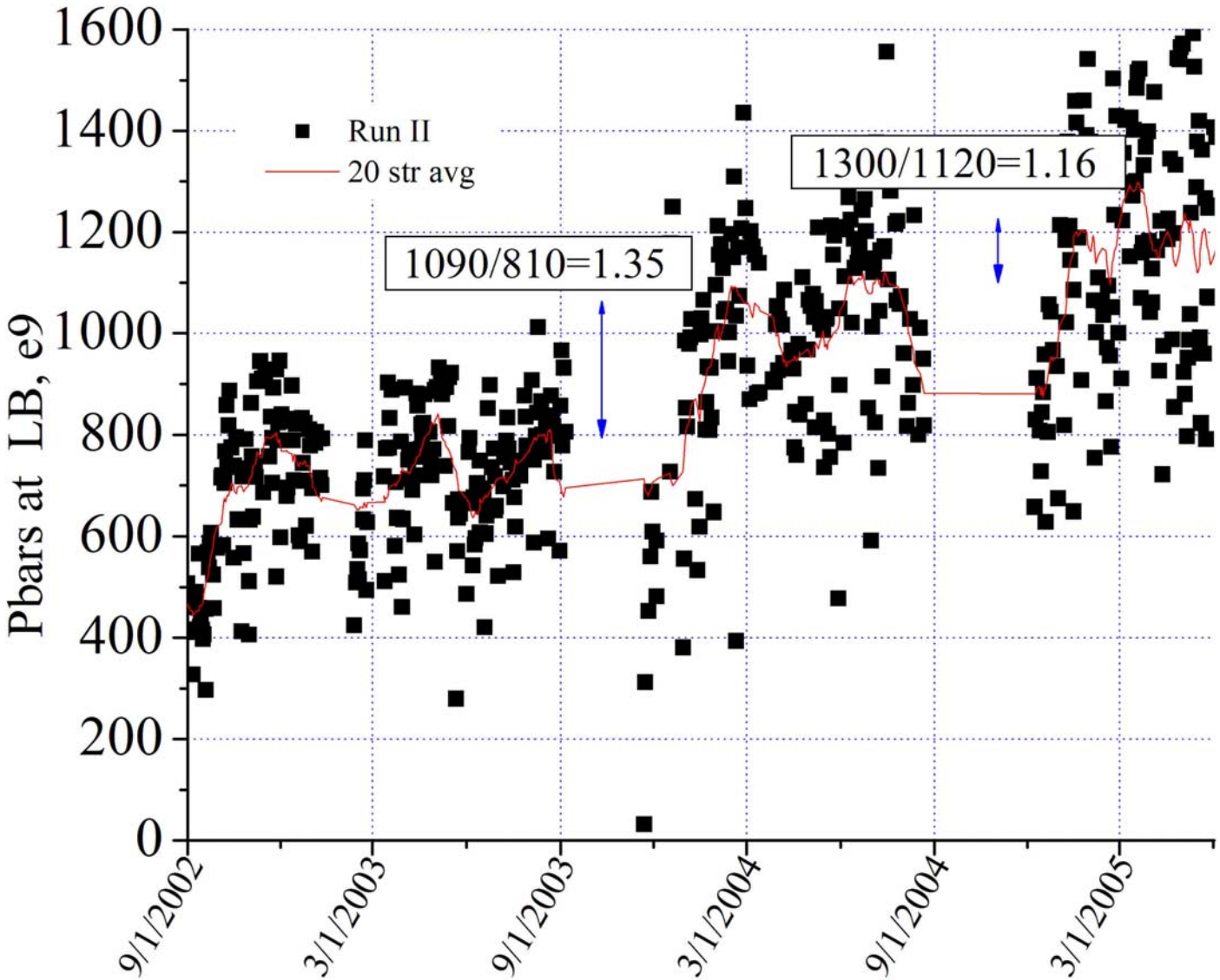
1/Effective Emittance from Luminosity



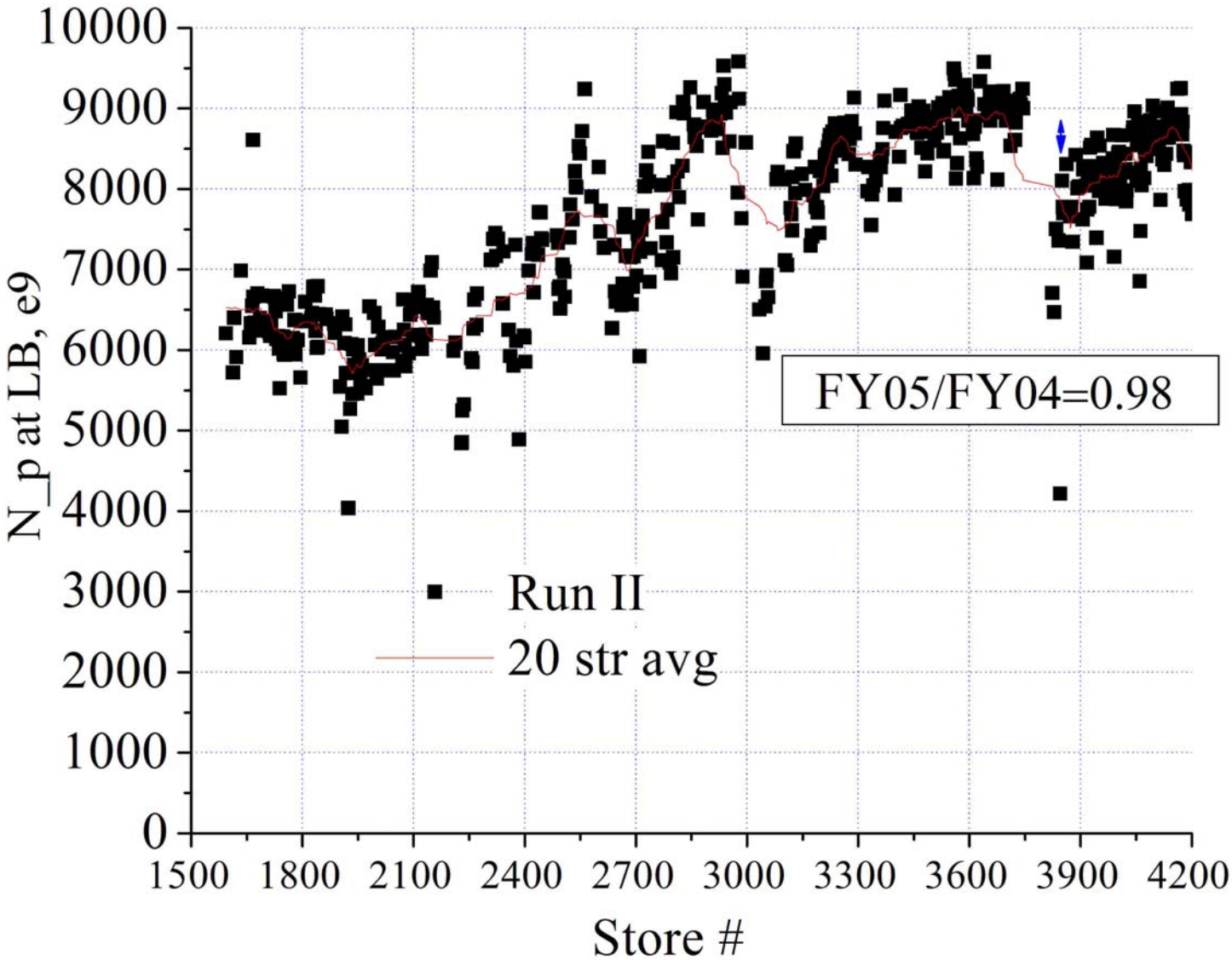
150 GeV Emittance from FW: TeV vs MI



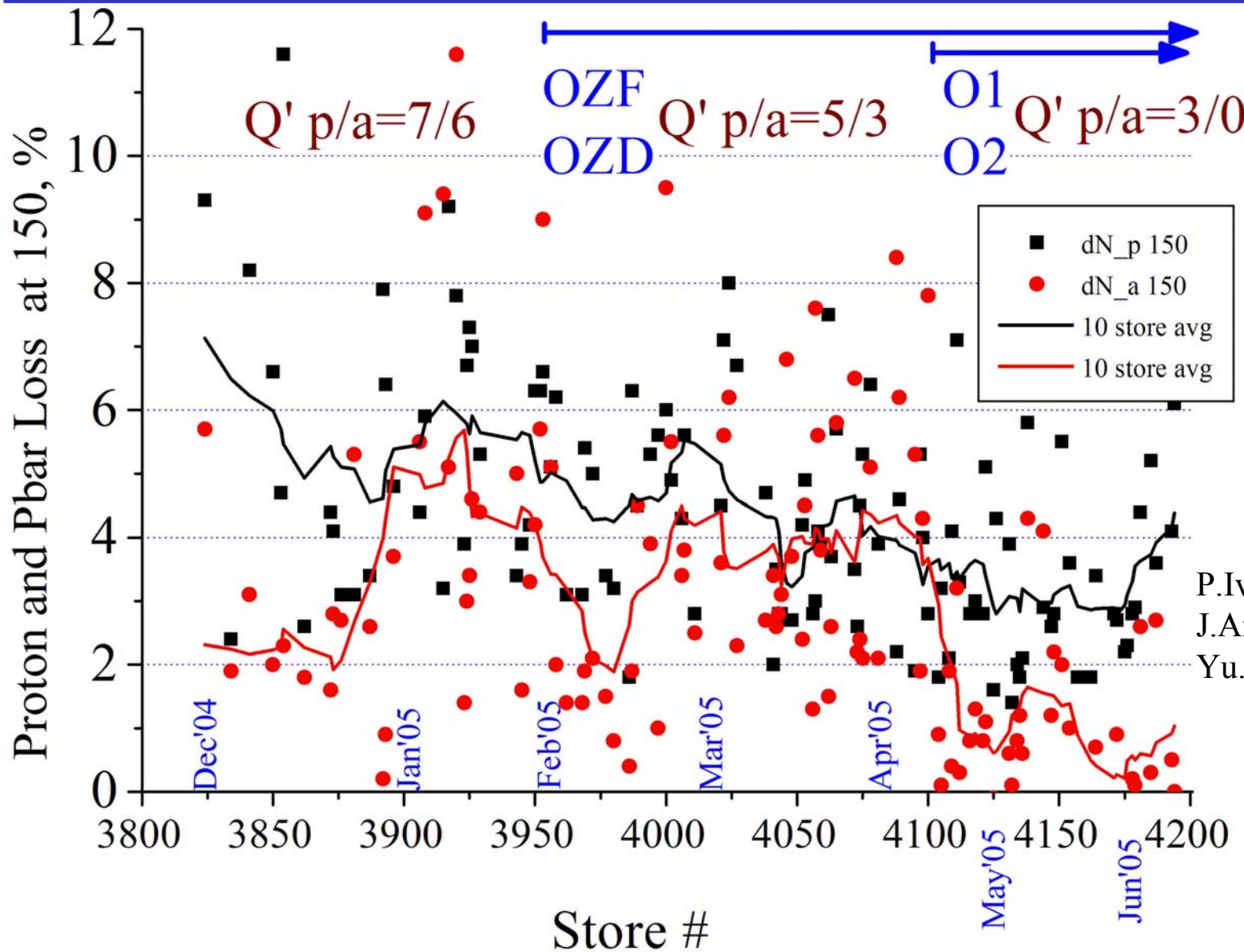
Pbars at Low Beta in Run II (Run Ib=540e9)



P's at Low Beta in Run II (Run Ib equiv 10000e9)

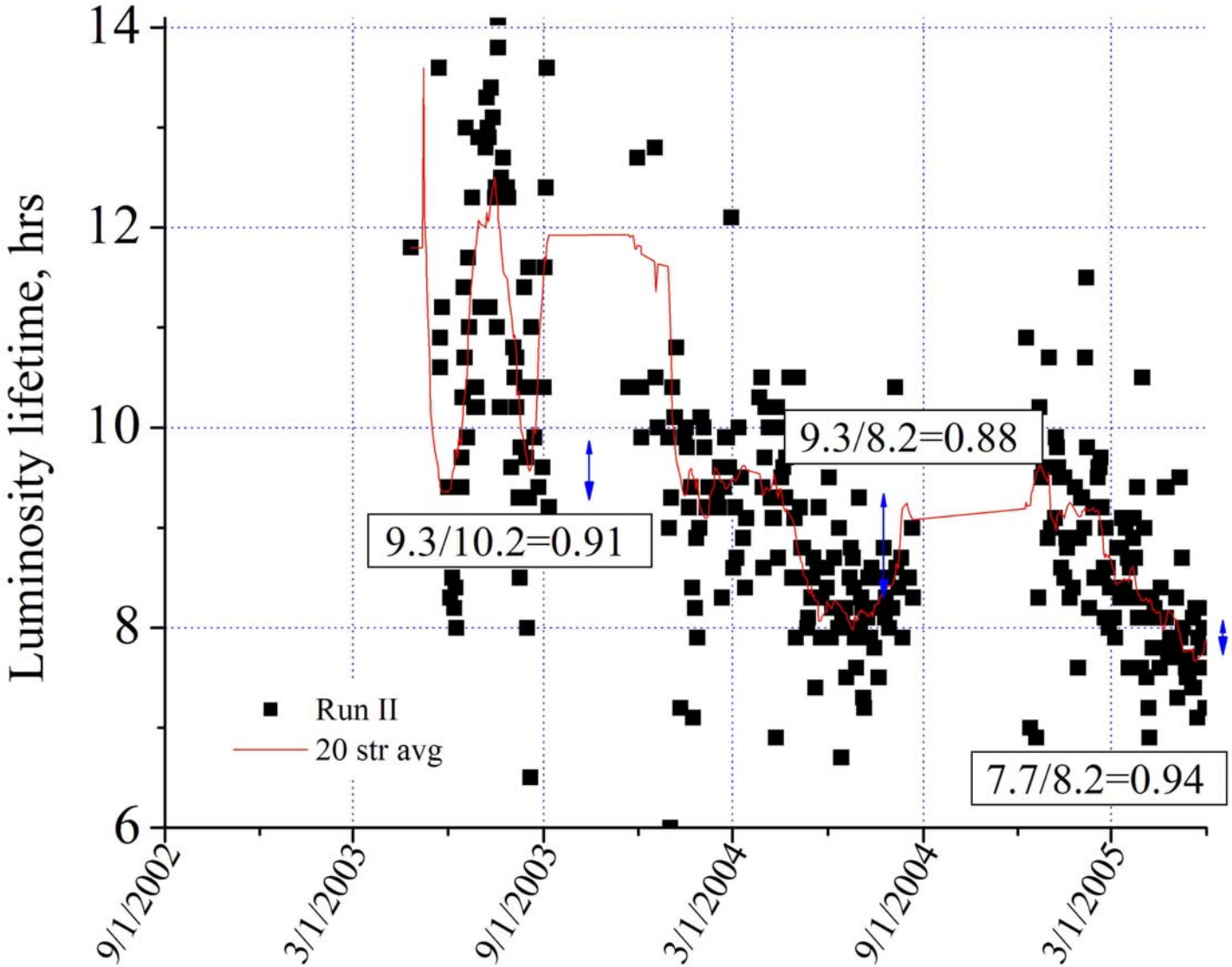


Octupoles to Drop Chromaticity Q'=dQ/(dp/p)

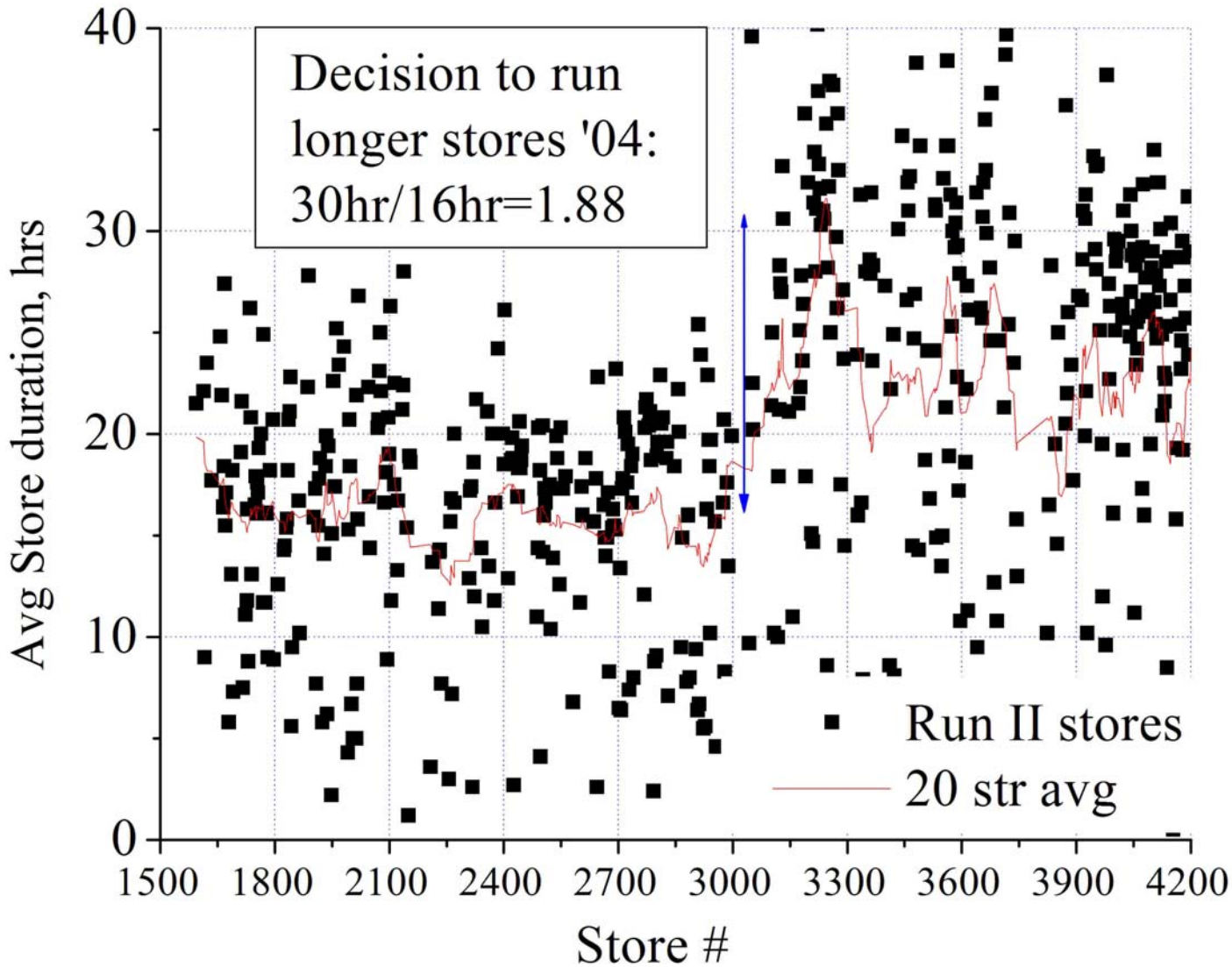


P.Ivanov
J.Annala
Yu.Alexahin

Luminosity Lifetime since 09/2002



Average Store Duration



$\mathcal{L}$-progress '02 – '03

"Sequence 13" fixed	Tev	Spring'02	x 1.40
"New-new" injection helix	Tev	Summer'02	x 1.15
"Shot lattice"	AA	Summer'02	x 1.40
Pbar emittance at injection	Tev/Lines	Fall'02	x 1.20
Pbar coalescing improved	MI	Fall'02	x 1.15
C0 Lambertson removal	Tev	Feb'03	x 1.15
S6 in Tev and SEMS in AP	Tev&AA	July'03	x 1.15

….plus additional improvements in the Tevatron:

- Tunes/coupling/chromaticities at 150/ramp/LB
- Orbit smoothing
- Longitudinal damper to stop σ_s blowup
- Transverse dampers improve 150 Gev lifetime
- Separator scans

$\mathcal{L}$-progress: Shutdown '03 – March '04

	Peak L	Int L	N_a	N_p	Emm_eff	RunTime
▪ Total progress	1.51	1.61	1.35	0.98	1.12	1.37
➢ Tev reshim	12%	9%			12%	
➢ 2.5MHz MI	8%	5%	8%			
➢ Tev dampers and Align	5%	3%	4%	2%?		
➢ StoreTime/Length	19%	19+16%	21%		-2%?	37%

$\mathcal{L}$-progress: Mar'04 – Jul '04

	Peak L	Int L	N_a	N_p	Emm_eff	RunTime
▪ Total progress	1.41	1.21	1.02	1.02	1.30	0.92
➢ Tev beta*	29%	20%?			29%	
➢ BmLoad MI	5%	4%?			5% in H(x)	
➢ Reliability		-8%				

$\mathcal{L}$-progress: Shutdown '04 – June '05

	Peak L	Int L	N_a	N_p	Emm_eff	Store T
▪ Total progress	1.32	1.19	1.16	0.98	1.24	1.0
➢ No Tev precycle		2%				
➢ Tev octupoles	7%	5%	4%	3%		
➢ RR mixed shots	25%	11%	12%		13%	
➢ ?(Tev Align/reshim)		5%?			11% ?	????

WARNING!:

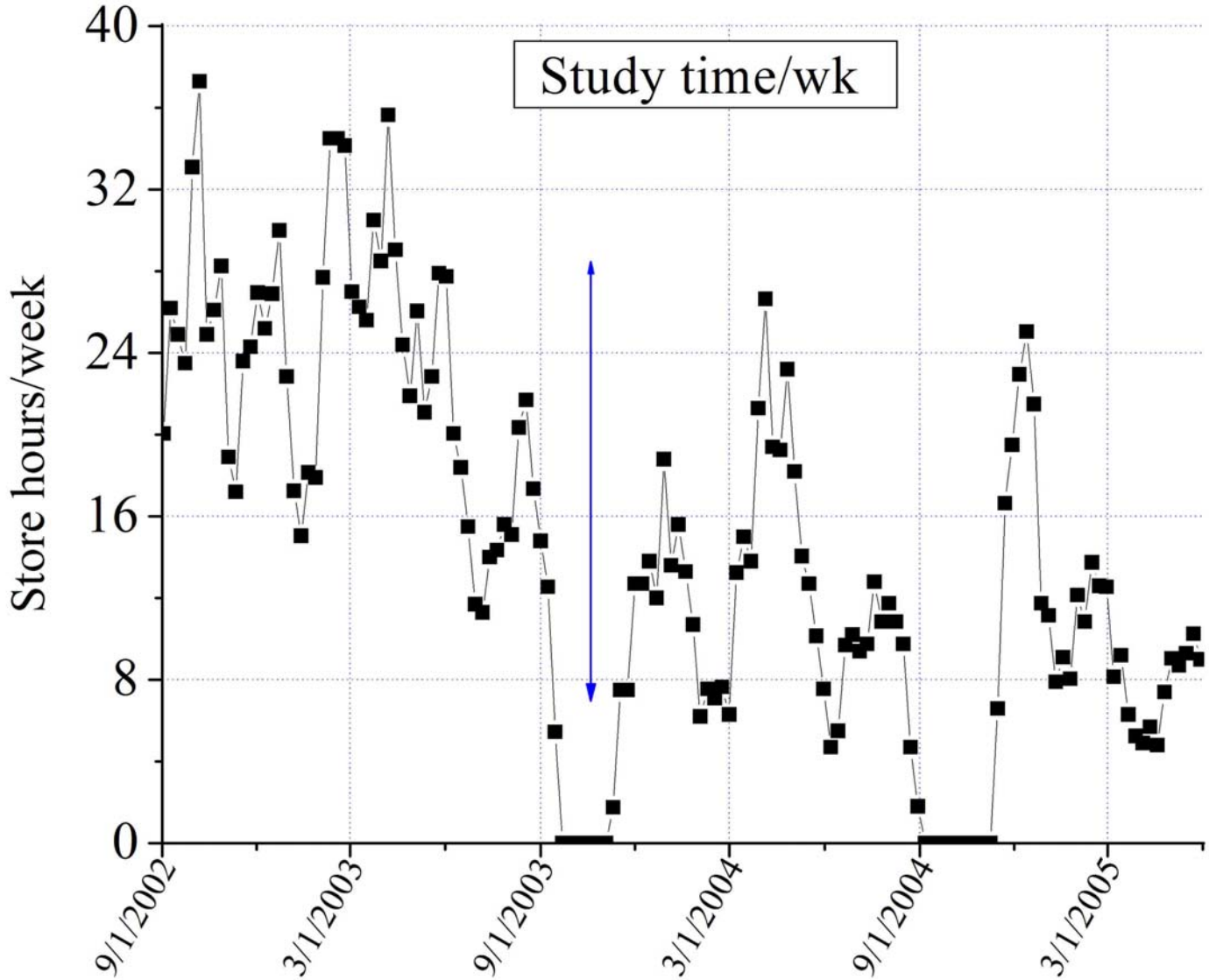
a) Error bars: +- 1 % for 2% effects

+- 3 % for 10% effects

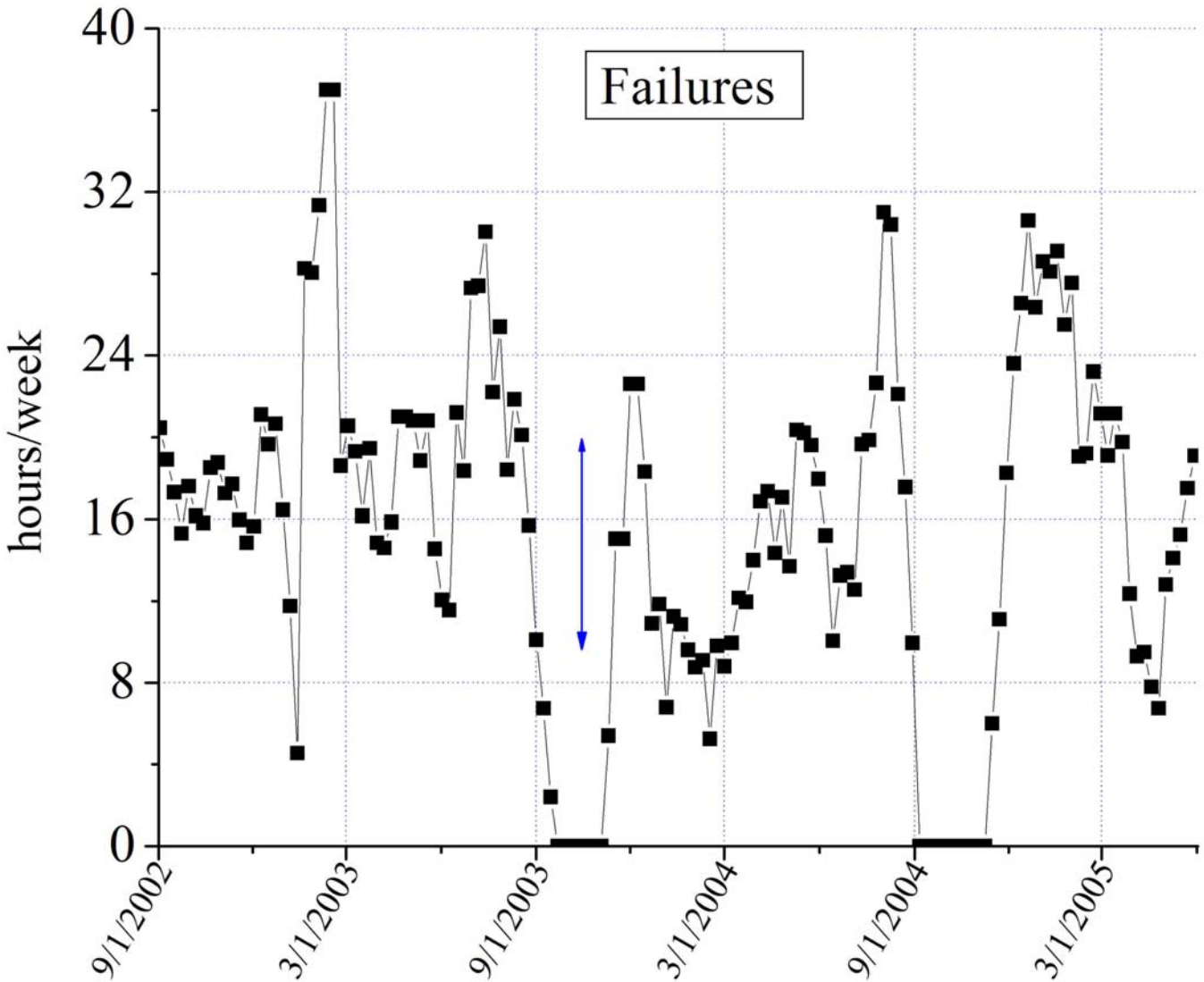
+- 5 % for 30-50% effects

b) "One man" vision & analysis

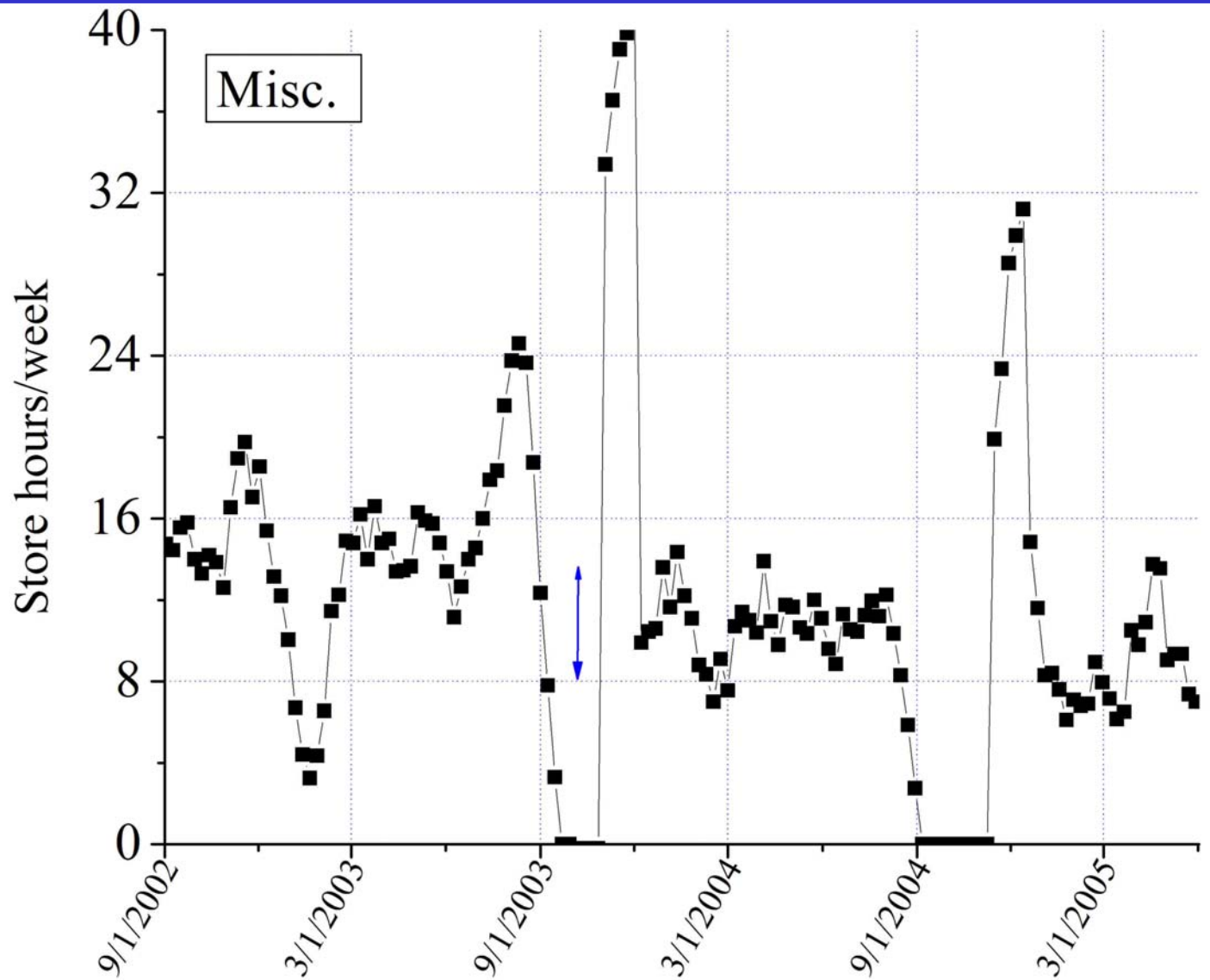
Study time hrs/wk since 09/2002



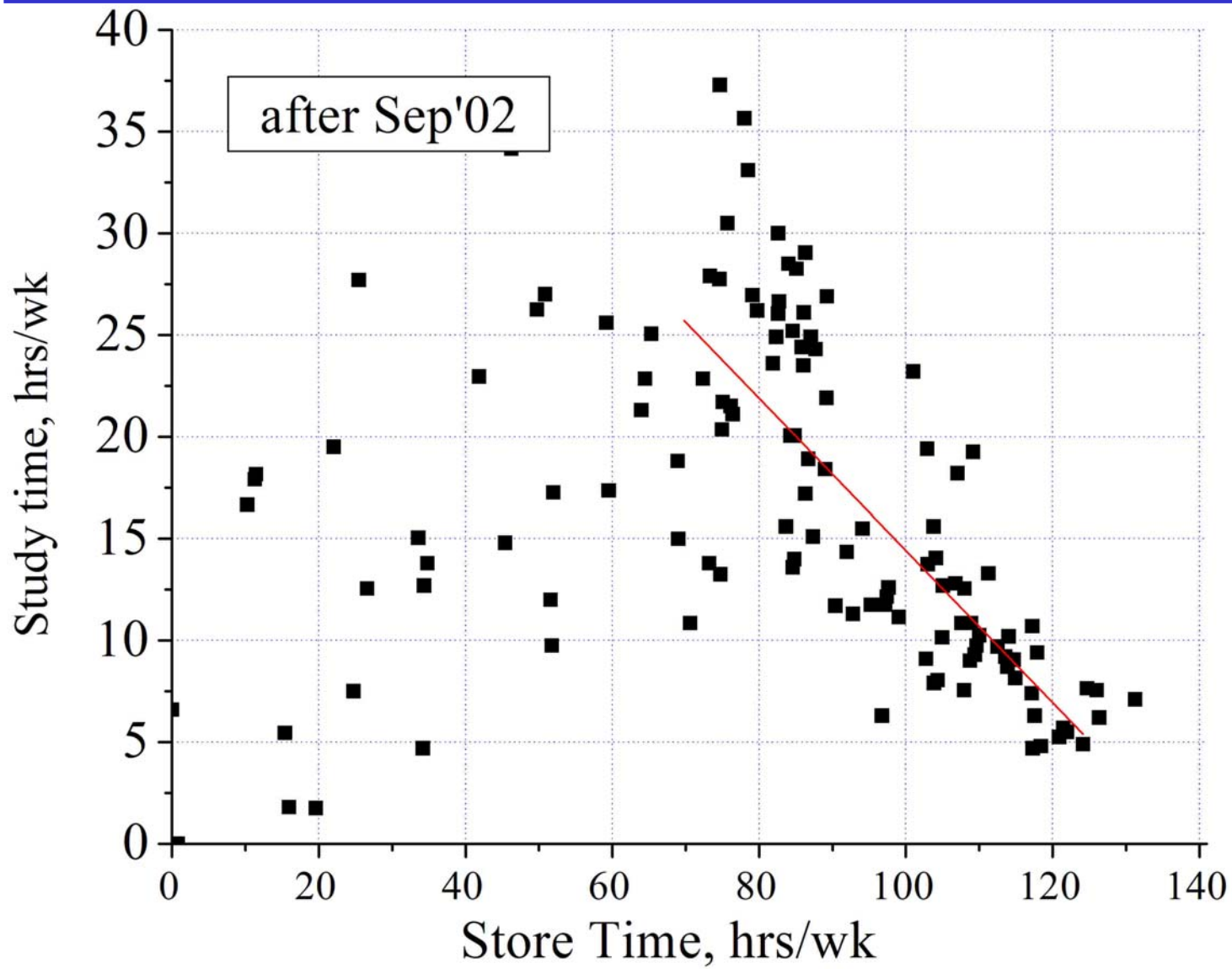
Failure (hrs/week): Tev failures, quench recovery, etc



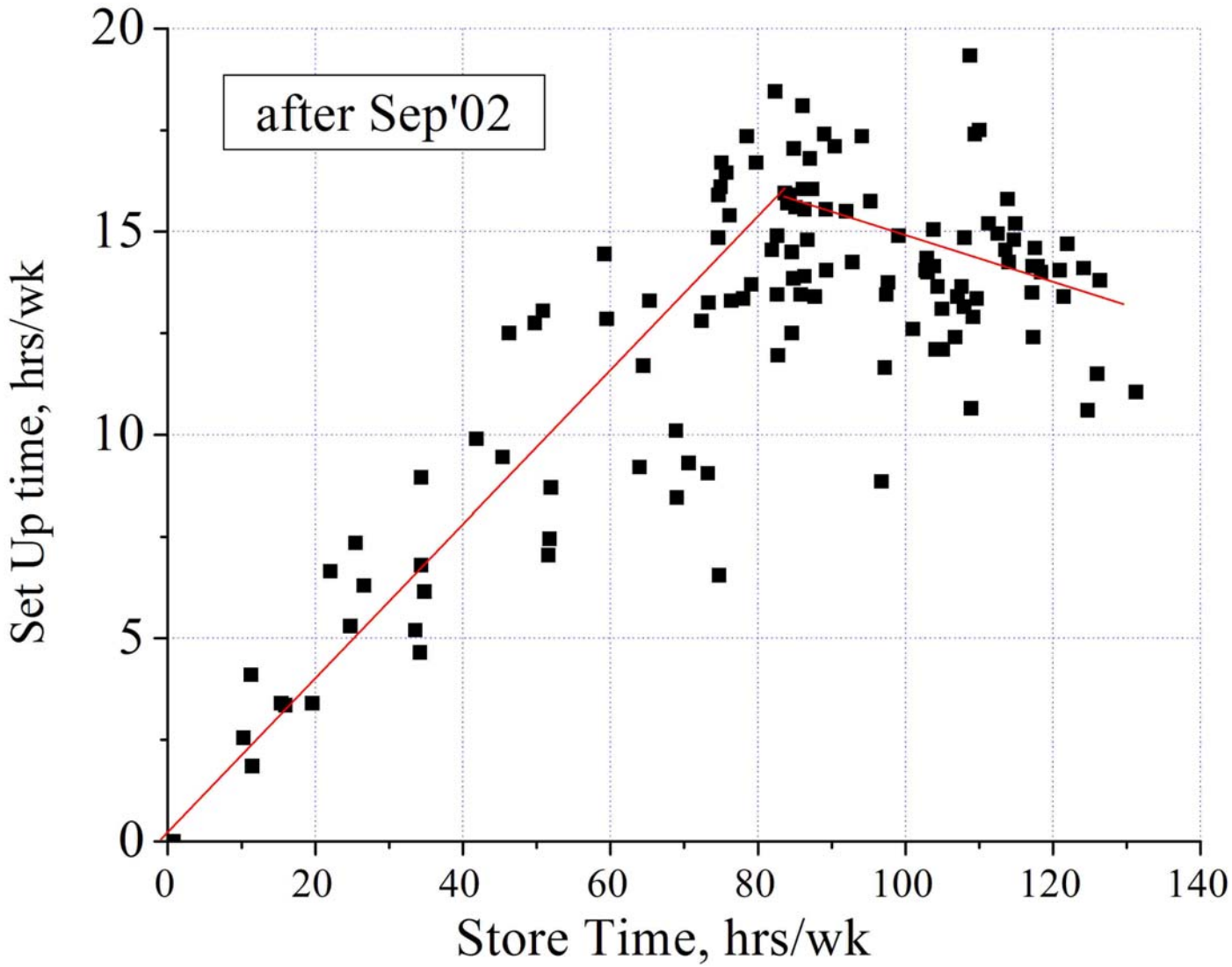
"Misc" time= detector access, startup, etc



Study time vs Store Hours/wk



Shot SetUp time vs Store Time/wk



Conclusions: I

- From Summer'03 to Summer'05, peak luminosity has grown by factor 2.8 (40→120e30) and weekly integrated luminosity by factor 2.3 (7.2→16.7 pb-1/wk)
- Most important improvements (>10%) came from:

	L_peak	L_int	
➢ RR mixed shots	25%	11%	studies
➢ Beta* change	29%	20%	studies
➢ MI 2.5MHz/BLC	13%	9%	studies
➢ Reliability/L-time	19%	36%	management
➢ Tev Reshim/Align	12%	9%	shutdown

  with additional detectable/recognizable contributions due to Tev octupoles, Tev precycle elimination, and Tev instability dampers

- Open question whether there was real emittance improvement in MI → TeV transfers after FY'04 shutdown

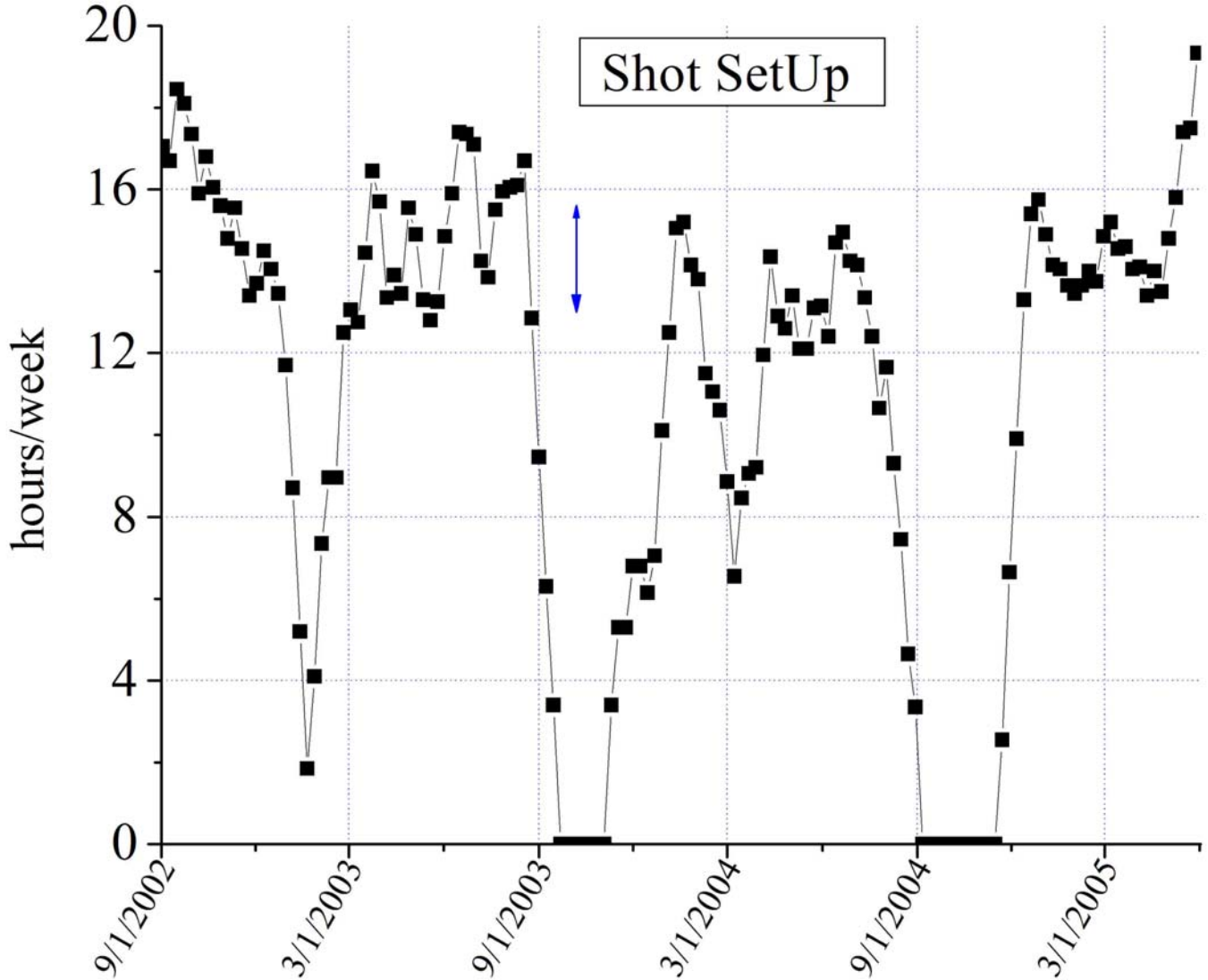
Conclusions II

- (Depending on above) Operation of the Recycler in "mixed source" mode led to 6-11% increase of weekly integrated luminosity in FY'05
- (Un)surprisingly, comparable RR effects come from both smaller emittances of pbar bunches and from higher pbar intensity
- Increase of the running time (+28 hrs) after FY'03 gave one time gain of 36% in luminosity integral. Most of the extra time came from study time reduction (-16hrs), more reliable Tevatron (-8hrs), and shorter "Misc" time (-4 hrs).
- Later in FY'04 and FY'05, the time in collision slipped back –(8..10) hrs, due to worsened reliability (partly compensated by further reduction of study time)
- As expected, statistics shows anticorrelation btw "Store time" (hrs/wk) and "Study" time, and btw "Store" and "SetUp" time

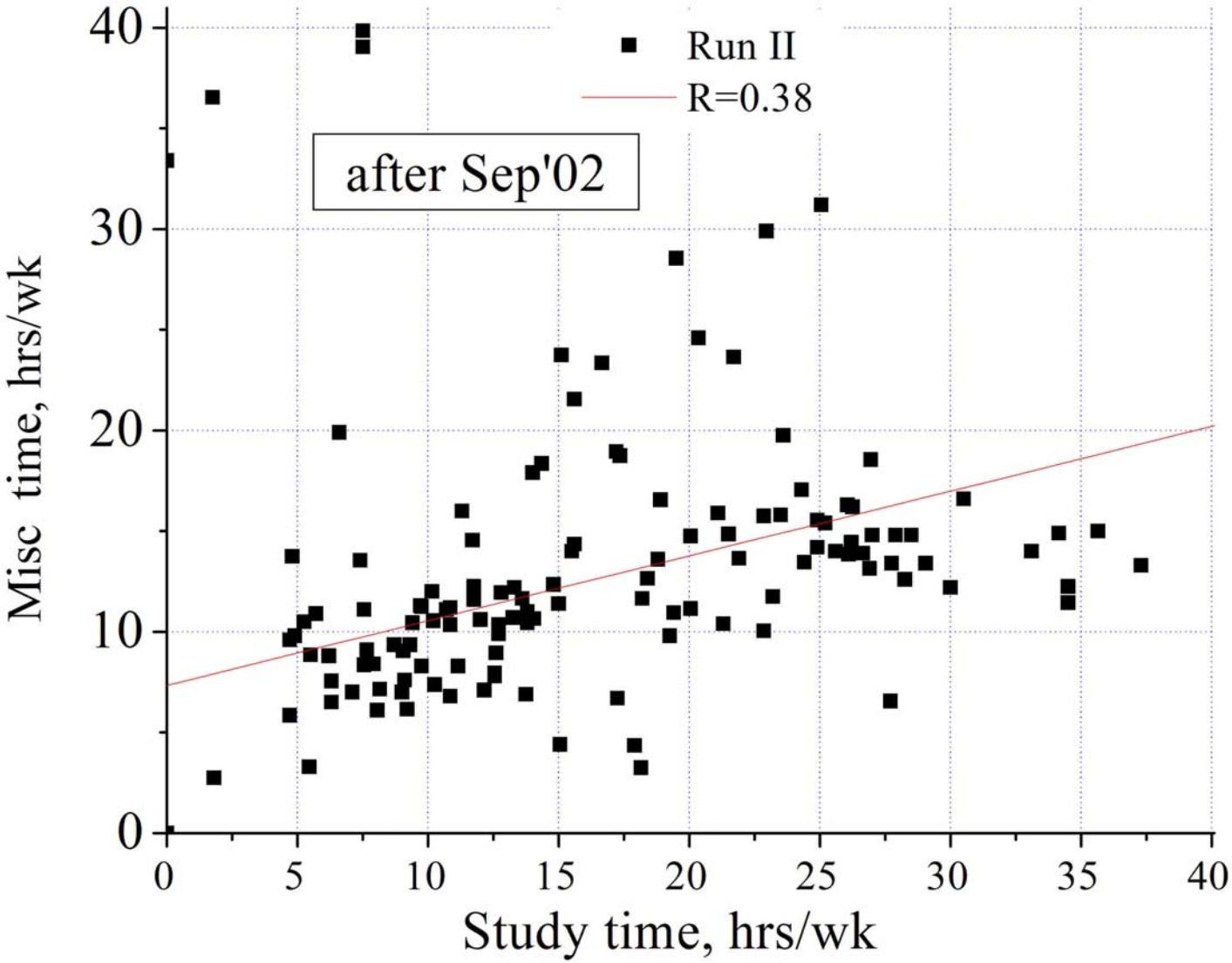
Thanks to Ioanis for emotional discussion on the subject

BACK UP SLIDES

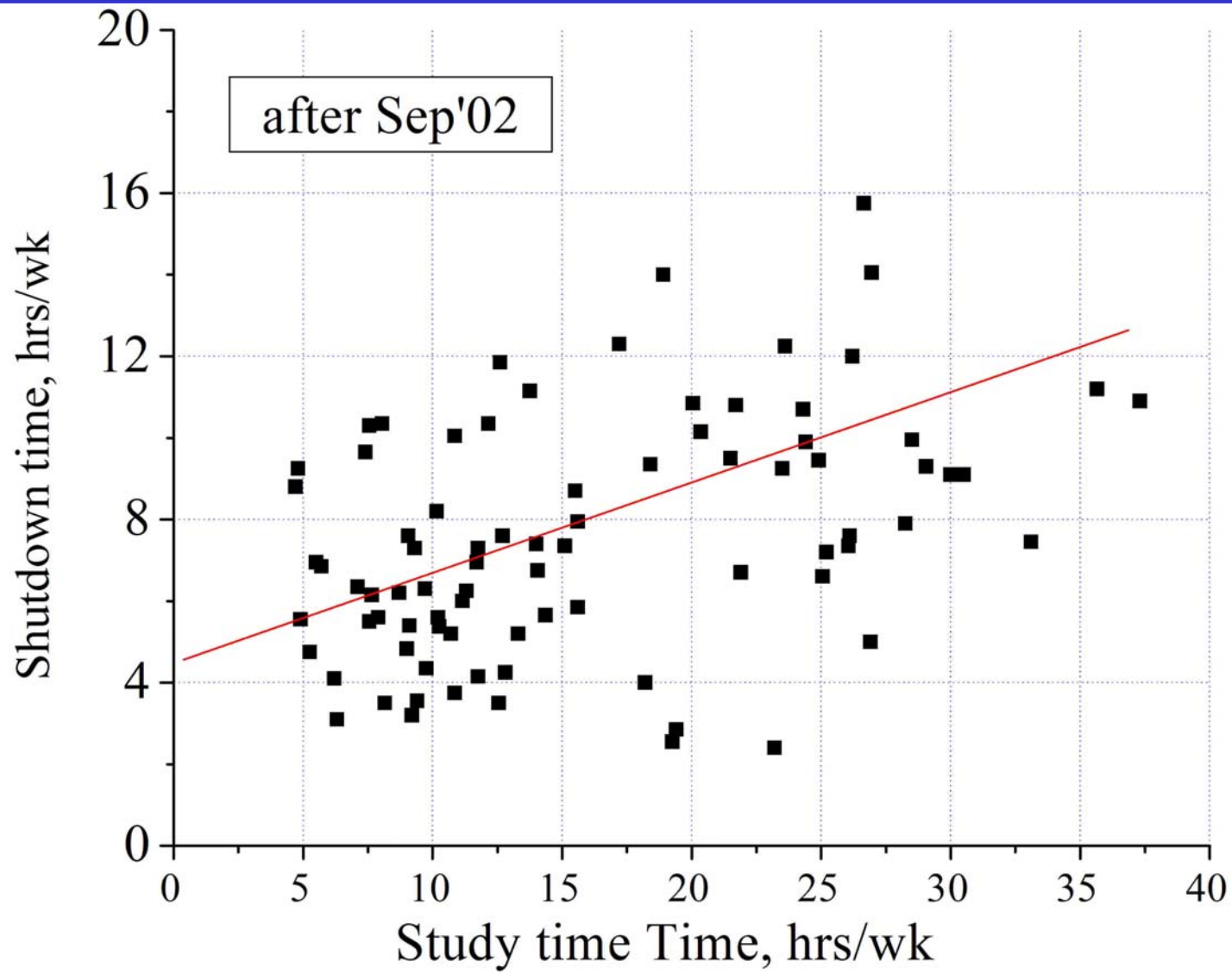
Shot SetUp time /wk in Run II



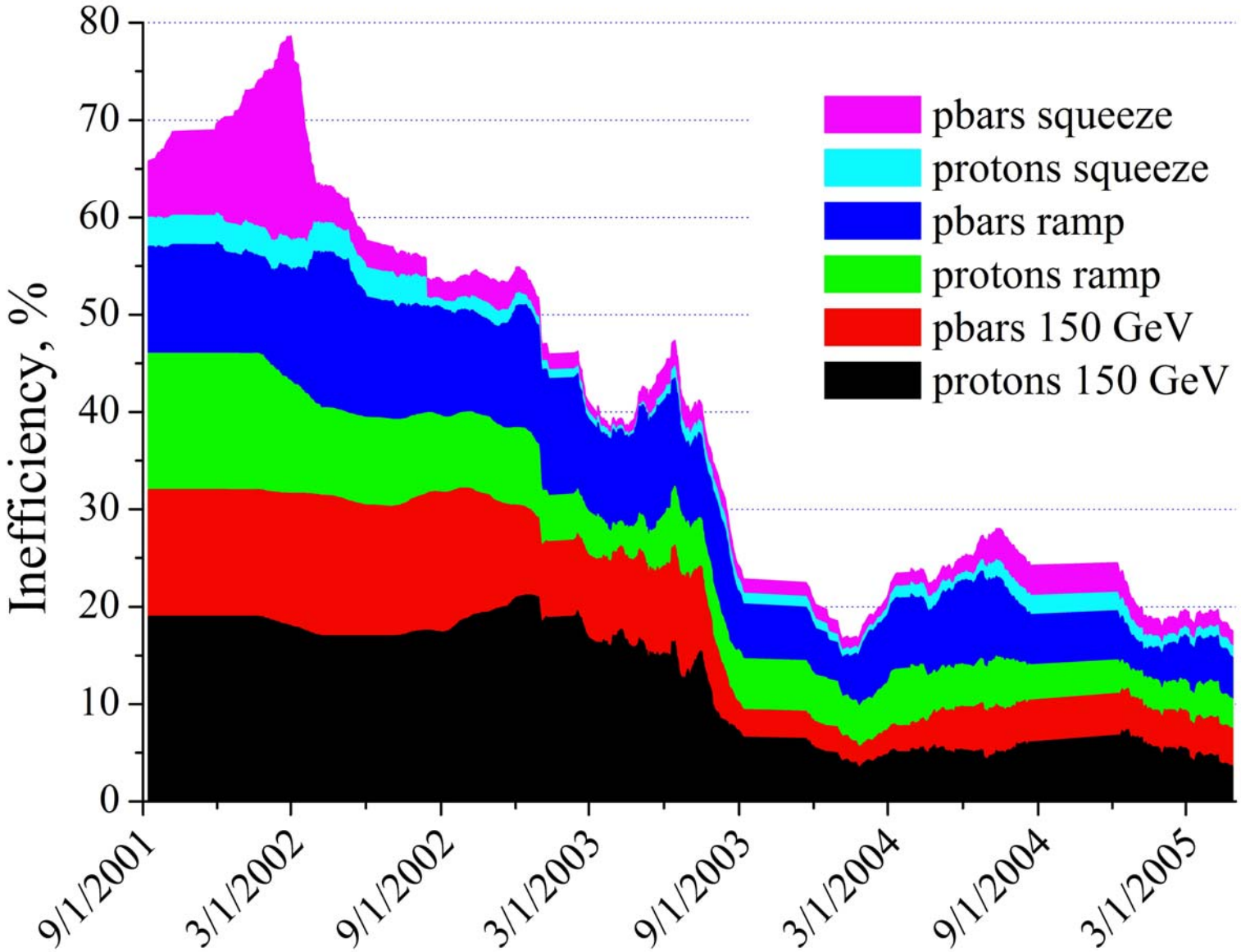
"Misc" time vs "Study" time – correlation?



Shot SetUp Time ~ Studies?



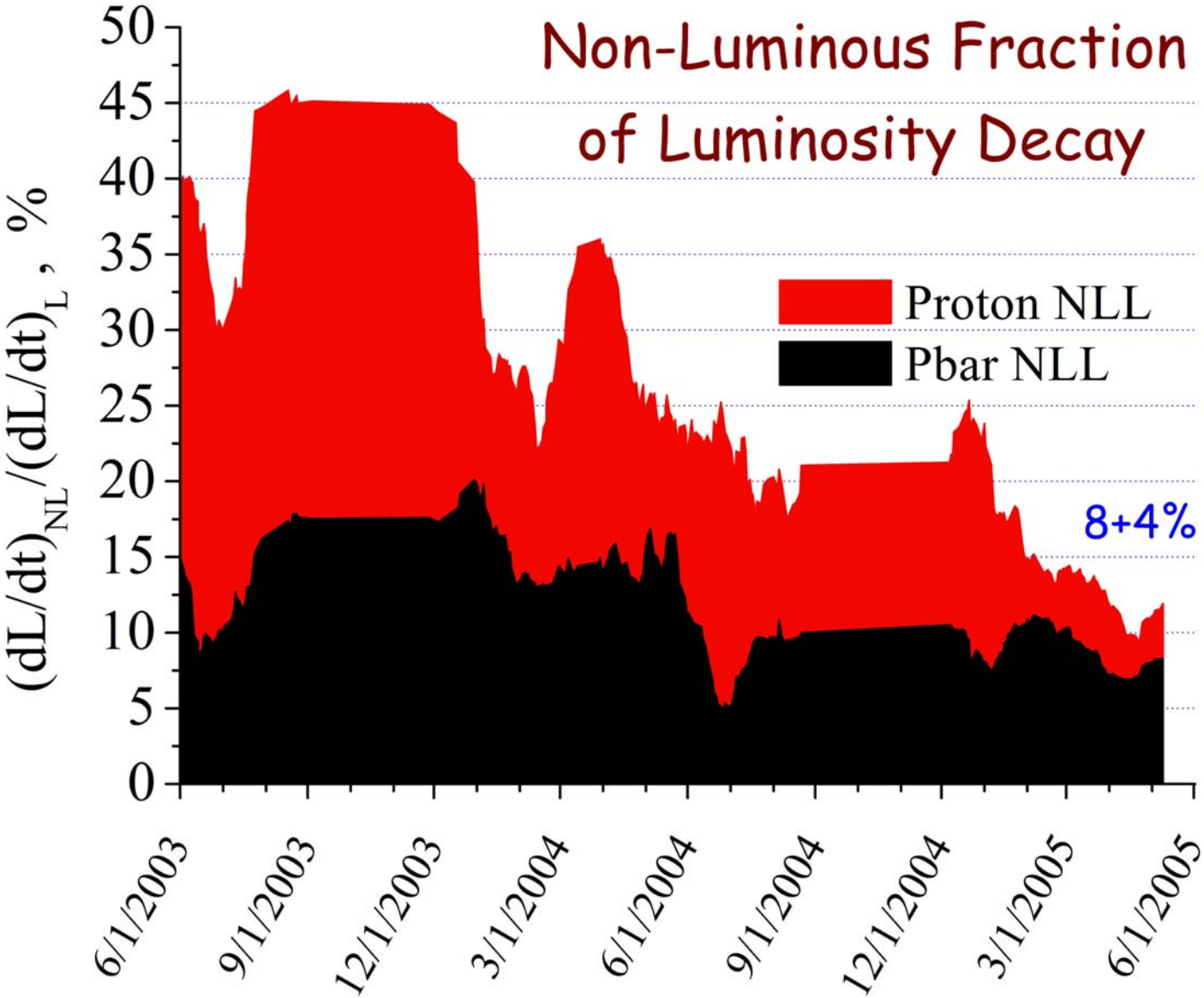
Tevatron Inefficiencies: 2001-2005



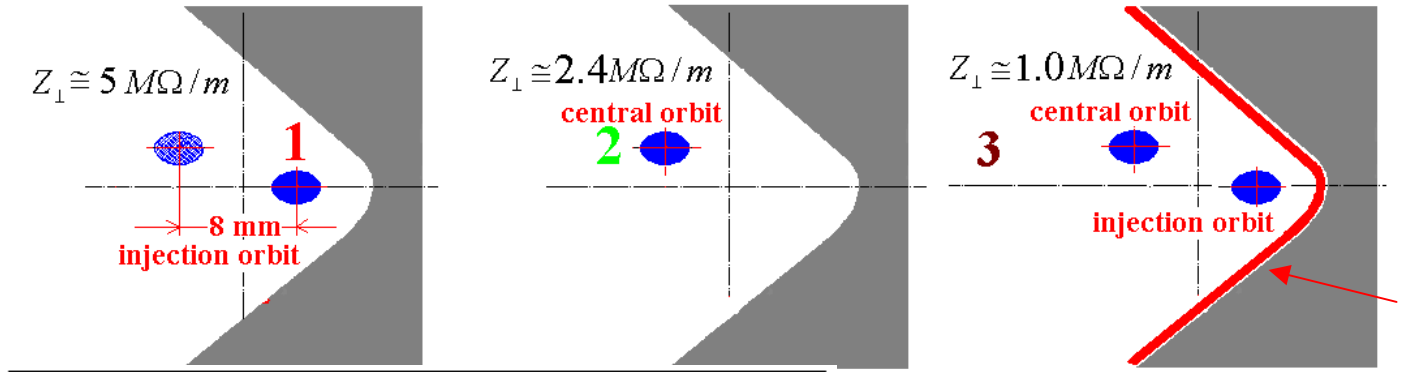
???

Jun 2009

L-Lifetime Affected by Beam-Beam

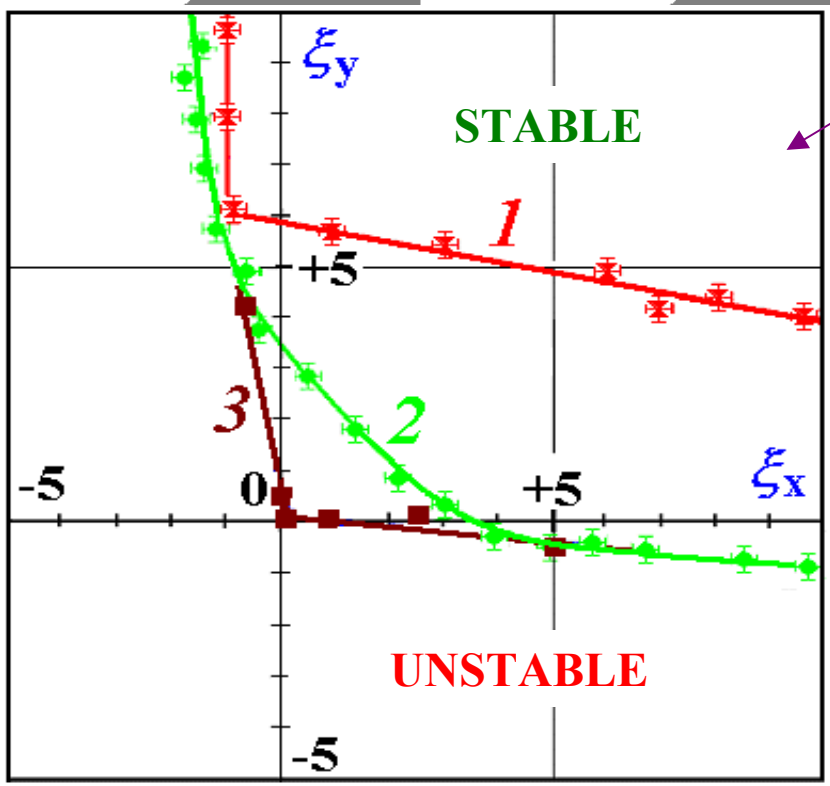


Tevatron Impedance



P.Ivanov
A.Burov
A.Chen

0.4 mm liner
CuBe (98+2%)



Region of stability of high intensity coalesced bunches (~230e9) on chromaticity plane before (#1 and #2) and after (#3) installation of conducting liner in F0 Lambertson magnets

Total transverse impedance reduced from 5-2.4 MOhm/m to 1 MOhm/m

Losses at 150 ~ Chromaticity

Octupoles to run at C_vh=0